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DEVELOPMENT OF A HYDRAZINE GAS-GENERATION SYSTEM FOR THE LARGE OBJECT SALVAGE SYSTEM (LOSS)

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Port Hueneme, California

December 1973

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K. W. Tate

ABSTRACT

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The hydrazine gas generation system was mated with the LOSS (Large Object Salvage System) pontoon developed by the Naval Coastal Systems Laboratory, Panama City, Florida, and successfully tested in a shallow water demonstration of the integral lift system. In this demonstration, a 74 L ton object was salvaged from a depth of 90 feet. The success of this in situ test demonstrated the suitability and practicality of using monopropellant hydrazine to produce large volumes of buoyancy gas.

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(PAGE 2)

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CONTENTS

Page

APPENDIXES

INTRODUCTION

Background

Prompted by the loss of the *USS Thresher* (SSN593) in April 1963, the Navy formed a Deep Submergence Systems Review Group to conduct an in-depth analysis of current underseas capabilities and propose future programs related to the location, identification, rescue of people, and recovery of objects from the deep ocean floor [1]. Based on the findings of this review Group, the Deep Submergence Systems Project was established, as well as several SOR (Specific Operational Requirements) for undersea search, rescue, and salvage. One such requirement, SOR 46-17, is to provide for the salvage of large objects, including sunken ships, from continental shelf depths.

From the initial LOSS (Large Object Salvage System [2]) study, completed in 1965, evolved several equipment development concepts and specifications, as well as the identification of surface ship characteristics which would be required to support salvage operations from continental shelf depths down to submarine collapse depths.

During the period from 1965 to 1970, individual components for salvage were under development. These components alone did not constitute a significant salvage capability, but were developed piece-by-piece and were not combined with other developments for a common purpose.

In 1970, under sponsorship of the Naval Ship Systems Command, a LOSS demonstration program was initiated. The objective of this program is to bring together the salvage components under development, applicable past developments in or out of the immediate area of salvage, into an operational demonstration, and thereby determine the course and direction of further large-scale salvage system developments.

As part of this LOSS demonstration program, NCEL developed a hydrazine-fueled gas generation system in order to establish the merits of this chemical gas generating technique in large salvage operations. The hydrazine system is contained within the rigid steel LOSS salvage pontoon and provides buoyancy gas both to pressure-compensate the pontoon against the external seawater pressure and to completely deballast the pontoon and create lift.

System Application

NCSL (Naval Coastal Systems Laboratory), Panama City, Florida designed and built the remotely operated pontoon used in the LOSS program. This pontoon has a total displacement of 200 L tons and a design lift capability of 100 L tons from a depth of 850 feet. A photograph of the LOSS pontoon under construction is shown in Figure 1.

Figure 1. Large Object Salvage System (LOSS) pontoon under construction at the Naval Coastal Systems Laboratory, Panama City, Florida.

The pontoon is internally divided into three compartments: one compartment in each end (dry chambers), and a center compartment (wet chamber). With the wet chamber flooded and the dry chambers pressurized with a buoyancy gas to the ambient seawater pressure, the pontoon is neutrally buoyant. Deballasting of the wet chamber with a buoyancy gas can create up to 100 L tons net lift. Four pontoon arms and remotely fired stud guns are used to attach the pontoon to an object to be salved. Two of the pontoon arms, folded under the pontoon, are visible in Figure 1. A wire rope and ballast chain drop mechanism are used to control the upward ascent of the pontoon and salvage object. The major features of the pontoon are shown schematically in Figure 2.

During the descent of the pontoon to the salvage object, buoyancy gas must be continually supplied to the dry chambers to maintain these compartments at the ambient seawater pressure. The pontoon can be lowered from the surface to a depth of 850 feet (392 psia) in four hours. After the pontoon has been attached to the salvage object, the center compartment is dewatered in 4 hours. The dry chambers represent half of the total volume of the pontoon, hence, half of the total buoyancy gas required is used during the descent phase of the salvage operation.

Two separate self-contained gas generation systems have been developed for the LOSS pontoon: liquid nitrogen[a] and hydrazine. This report describes the development and operation of the hydrazine gas-generation system.

Hydrazine Characteristics

Hydrazine (N_2H_4) is a clear, water-white liquid with an odor similar to ammonia. It is stable to friction and shock and completely miscible in either fresh or seawater. Anhydrous hydrazine is a liquid under normal conditions of pressure and temperature; the normal freezing point is $35^{o}F$ and the normal boiling point is $236.3^{o}F$ [3]. Liquid hydrazine in the presence of a suitable catalyst will decompose into hydrogen, nitrogen and (possibly) ammonia gases. This evolution of a large volume of low-molecular-weight, noncondensable, gases is particularly important for underwater buoyancy. Because of the simplicity of operation and the large volume of gas which can be realized relative to the volume of liquid, hydrazine is well suited for salvage buoyancy applications.

The decomposition of hydrazine is an exceedingly complex phenomena. For discussion purposes, hydrazine decomposition is generally considered to take place in the following stepwise manner:

$$3N_2H_4 \rightarrow 4NH_3 + N_2 + 144{,}300\ \text{Btu} \qquad (1)$$

$$4NH_3 \rightarrow 4(1-X)NH_3 + 2XN_2 + 6XH_2 - 79{,}200\,X\ \text{Btu} \qquad (2)$$

In the first reaction hydrazine undergoes exothermic decomposition forming ammonia and nitrogen. The energy released from the first reaction provides the driving force for the endothermic dissociation of ammonia into hydrogen and nitrogen. In practical systems of interest, the second reaction does not go to completion due to long reaction times [4], and thermodynamic equilibrium considerations of hydrogen-nitrogen-ammonia mixtures [5]; hence, **X** is used to indicate the fraction of ammonia dissociated. The effect of ammonia dissociation on the relative volume of gases produced is shown in Figure 3. Complete ammonia dissociation results in the largest volume of gas, on a volume basis for **X** = 1, the gas is composed of two-thirds hydrogen and one-third nitrogen. At 50% ammonia dissociation (**X** = 0.5), the total gas volume is 78% of the gas volume for complete dissociation and the gas composition is 42% hydrogen, 30% nitrogen, and 28% ammonia. If none of the ammonia is dissociated, the total gas volume is only 55% of that for complete dissociation and is composed of 20% nitrogen and 80% ammonia. The extreme solubility of ammonia in seawater and its relatively high vapor pressure (130 psia at $70^{o}F$)[b] make ammonia unsuitable as a buoyancy media. Hence, the solid line shown in Figure 3 represents the relative gas volume available for buoyancy as a function of ammonia dissociation. It is clearly evident that a high degree of ammonia

[a] Developed by NCSL, Panama City, Florida.

[b] Conditions at which ammonia will condense into a liquid.

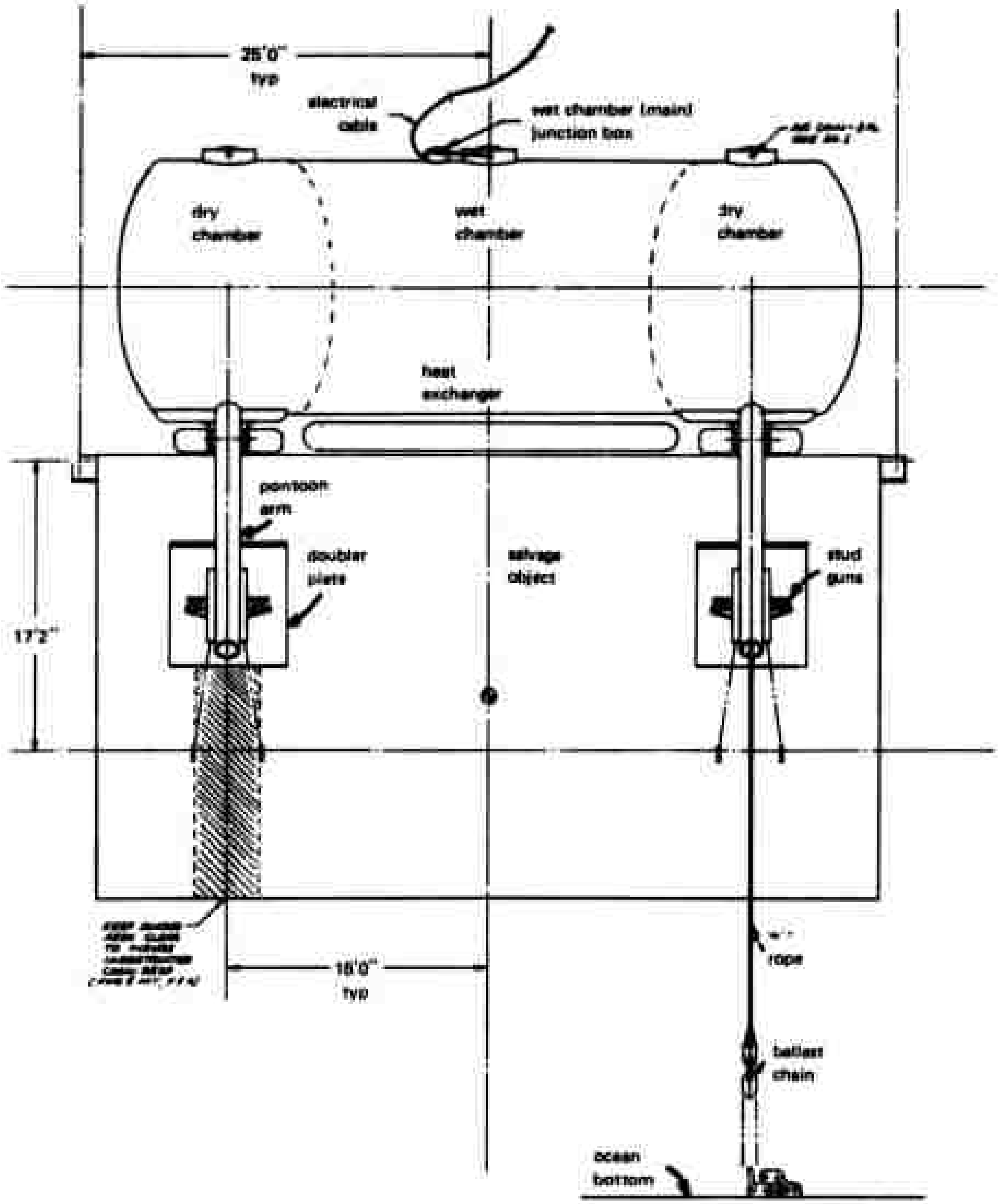

Figure 2. Schematic of the pontoon attached to a simulated salvage object.

dissociation is requisite in underwater buoyancy applications.

In an empirical investigation by Schmitz, et al. [3], ammonia dissociation levels of 85 to 75% were obtained over an investigated pressure range of 50 to 1,000 psia. An ammonia dissociation level of 80% was adopted for design purposes in the present investigation.

The total quantity of hydrazine needed to fulfill buoyancy gas requirements is dependent upon the maximum depth encountered, the total volume of seawater to be displaced, and the fraction of ammonia dissociated. The solid line in Figure 4 shows the relation between buoyancy factor (weight of seawater displaced per unit weight of hydrazine reacted) and fraction of ammonia dissociated (X) for a depth of 850 feet and an ambient temperature of 70°F. At X = 1.0 the buoyancy factor is 87 lb/lb but decreases linearly to 10 lb/lb at X = 0.0. For X = 0.8 (design point) the buoyancy factor is 71.5 lb/lb. Thus, 6,266 pounds (750 gallons) N_2H_4 will be required to displace 200 L tons seawater at these conditions. The dotted curve shown in Figure 4 indicates the relative increase in the quantity of hydrazine required if the ammonia dissociation level is less than 1.0. This curve increases sharply with decreasing X, and at X = 0.8, 22% more hydrazine is required relative to X = 1.0.

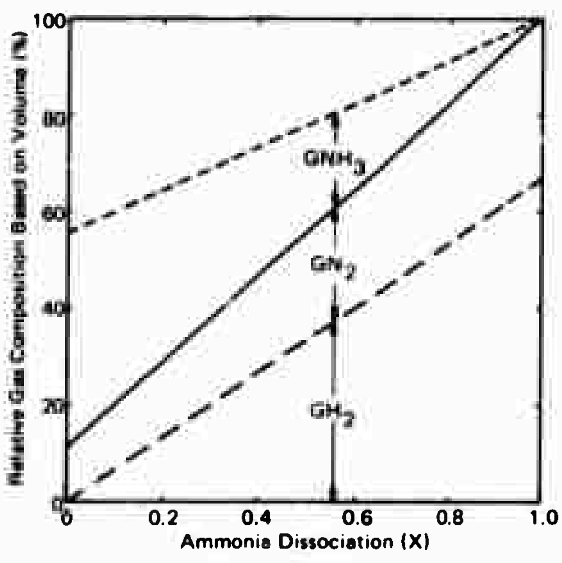

Figure 3. The effect of ammonia dissociation on the decomposition products of hydrazine.

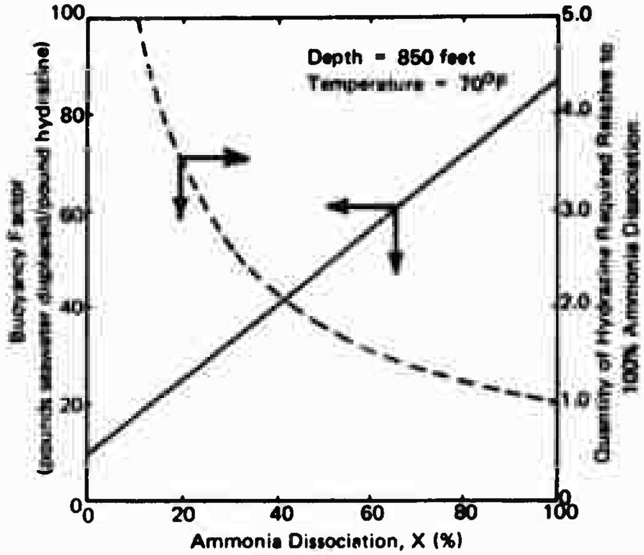

Figure 4. The effect of ammonia dissociation on the volume of buoyancy gas produced at 850 feet and 70°F.

SYSTEM DESCRIPTION

Photographs of the completed hydrazine gas-generation system are shown in Figures 5 and 6. Liquid hydrazine is stored in the large sphere in the center of the assembly. Gaseous nitrogen (GN_2), stored in additional tanks, is used to pressurize the hydrazine tank and to purge the system of residual liquid hydrazine after shutdown. Nitrogen delivered to the hydrazine tank is regulated to the desired pressure by a remotely operated pressure regulator. The hydrazine tank pressure governs the liquid hydrazine flowrate and hence the rate of gas generation.

Liquid hydrazine passes under pressure from the bottom of the hydrazine tank through 1/2-inch stainless steel tubing into the monopropellant gas generator (MGG). The MGG consists of a catalyst bed which decomposes the liquid hydrazine into the buoyancy gas and an injector which distributes the incoming liquid over the catalyst bed. The temperature of the gas leaving the MGG is approximately 1,400°F. A heat exchanger is used to cool the buoyancy gas to the ambient seawater temperature. The buoyancy gas exiting the heat exchanger is used to either pressure balance the pontoon or dewater the center compartment.

The hydrazine system has a rapid start characteristic. Full gas flow is achieved within 3 seconds from initiation of liquid flow at all conditions of temperature and pressure. The use of a completely

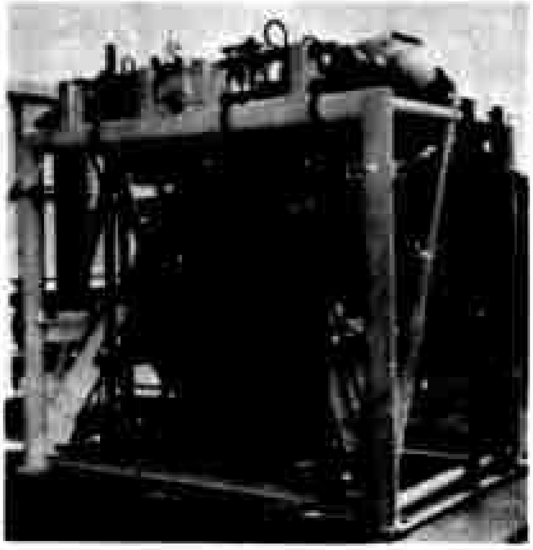

Figure 5. Hydrazine gas-generation system.

Figure 6. Hydrazine gas-generation system showing gaseous nitrogen storage containers.

spontaneous hydrazine catalyst allows many restarts of the hydrazine system without degradation of performance. Precise control of the gas generation rate is achieved by adjustment of the hydrazine tank pressure.

All pressure dependent or pressure sensing components used in the hydrazine system are designed to compare the internal system pressure and the external system (pontoon internal) pressure. Hence, changes in ambient pressure caused by changes in depth are automatically compensated for, making manual adjustments unnecessary.

The hydrazine system is located in the forward dry chamber of the pontoon. A photograph of the hydrazine assembly during installation in the pontoon is shown in Figure 7. The assembly is welded to a bed plate in the pontoon by the pads located at the base of the four vertical columns. The entire system is designed to withstand shock loadings of 4 gravitational units (g's) in the horizontal plane and 3 g's in the vertical plane.

The hydrazine system is remotely operated from a console aboard a surface support craft. A photograph of the console is shown in Figure 8. A color-coded piping diagram imprinted on the front of the console aids the operator in visualizing the flow situation. The system is equipped with pressure, temperature, and flow rate sensing instruments which monitor the operation of the system. The flow parameters measured are:

GN_2 supply pressure

GN_2 purge pressure

N_2H_4 tank pressure

N_2H_4 liquid flowrate

N_2H_4 inlet temperature to the MGG

Exhaust gas temperature from the MGG

Readout of these parameters is via panel meters appropriately located on the console.

The detailed step by step operating procedure for the hydrazine system is contained in Appendix A. Basically, this procedure consists of pressurizing the hydrazine tank by setting the N_2H_4 pressure regulator to a desired pressure and opening the N_2H_4 pressurizing valve. When the hydrazine tank pressure has stabilized, the two liquid N_2H_4 shut-off valves are opened allowing hydrazine to flow into the MGG. The instruments are checked to verify proper operation of the system and to establish the rate of gas generation. Flow is stopped by closing the two liquid N_2H_4 shut-off valves and briefly opening the GN_2 purge valve to push the residual hydrazine remaining in the delivery line through the MGG.

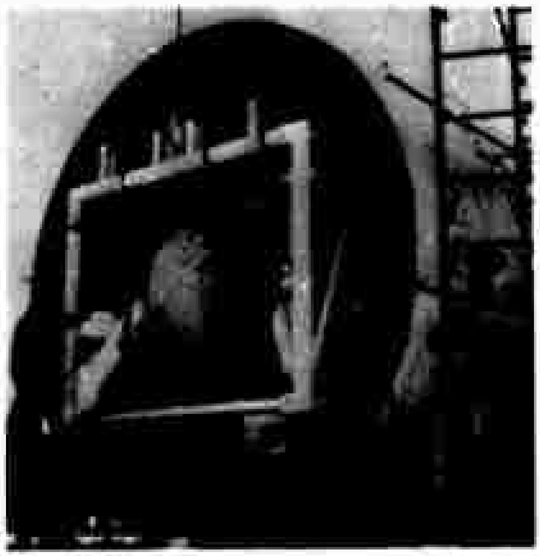

Figure 7. Hydrazine gas-generation system being installed in pontoon.

COMPONENTS DESCRIPTION

Hydrazine Tank

The hydrazine tank is fabricated of SA-240 TP 304 stainless steel, has an internal diameter of 72 inches, a wall thickness of 0.388 inches, and is ASME coded for 400 psig. This tank can contain a maximum of 800 gallons liquid hydrazine with 5% ullage. The calculated hydrazine requirement was 750 gallons.

Tank openings consist of two 1/2-inch pipe couplings welded to the vessel at both the top and bottom of the tank.

Four support lugs welded to the tank wall are used to support the tank in the hydrazine frame. These lugs are designed to withstand shock loadings of 4 g's in the horizontal plane and 3 g's in the vertical plane without damage to the tank.

Monopropellant Gas Generator

A photograph of the MGG prior to assembly is shown in Figure 9 and a cross-sectional drawing of the assembled reactor is shown in Figure 10. The hydrazine injector is a showerhead type containing 25 orifices, each 0.0210 inch in diameter, which distribute the liquid hydrazine over the catalyst bed. The injector is bolted to the generator body and sealed at the mating flange by a silver plated stainless steel O-ring.

The catalyst bed is 3 inches in diameter by 6 inches long and is tightly packed with 1/8-inch-diameter by 1/8-inch-long cylindrical pellets of Shell 405 Catalyst. This catalyst, proprietary to the Shell Development Company, Houston, Texas, consists of an active metal impregnated into alumina granules and will initiate spontaneous decomposition of liquid hydrazine. The catalyst is held in place by the injector face, which acts as the upper bed support, and a 3/16-inch-thick lower bed support containing 149 holes, each 0.093 inch in diameter. The MGG is fabricated from 347 stainless steel, except for the lower bed support which is inconel 600. The side walls of the catalyst bed are covered with a zirconium oxide coating, 0.06 inch thick, to minimize radial heat loss from the bed.

Gaseous Nitrogen Supply System

Gaseous nitrogen is used to pressurize the hydrazine tank and to purge the MGG of residual hydrazine after reactor shutdown. The nitrogen supply system is composed of six high-pressure tanks, connected by a common manifold. Two spheres (located at the top of the assembly in Figure 6) were available from previous NCEL programs. These spheres, fabricated of 304 stainless steel, have an internal diameter of 27.25 inches, a wall thickness of 1.31 inches, and are ASME coded for 3,304 psig. Each sphere contains 1,382 SCF of nitrogen at a pressure of 3,319 psia.

Tank openings consist of ports drilled and tapped for 1/2-inch NPT located at both the top and bottom of each sphere.

Two support lugs welded to the tank walls are used to fasten the spheres to the hydrazine frame.

The remainder of the nitrogen supply system consists of four commercially available nitrogen cylinders (shown at each corner of the assembly in Figure 6). These cylinders have a maximum working pressure of 3,600 psig and a maximum nitrogen capacity of 350 SCF. In the present configuration

these cylinders are filled with 321 SCF nitrogen (3,319 psia). If required, however, larger capacity/higher pressure cylinders and a dual manifold system could be used to substantially increase the nitrogen storage capacity.

Support Frame

The support frame is the main structural member of the hydrazine system. The frame is fabricated of A-36 steel and protected with Devran (Formula 203), an anticorrosion epoxy coating. The liquid hydrazine tank and the nitrogen supply tanks are bolted directly to the support frame. The smaller system components (valves, regulators, tubing, etc.) are fastened to Unistrut framing which is in turn bolted to the support frame. The use of this framing allowed considerable versatility in locating and supporting the smaller system components.

Valves

Solenoid Valves. Valves used in the remote operation of the hydrazine system are underwater solenoid valves specially constructed by Pyronetics, Inc. These valves are suitable for both liquid hydrazine and gaseous nitrogen service and have an internal pressure rating of 3,300 psig and an external pressure rating of 1,350 psia (3,000 feet). The valve body is hard anodized aluminum and contains a stainless steel poppet and ethylene-propylene seals. The operating voltage is 110 Volts A.C. and the electrical connection is an underwater Kintec connector (part number HS2-2BPX-MWT2).

Hand Valves. Dragon model 816 stainless steel hand valves are used in the hydrazine system to isolate components during various system checks. These valves have a pressure rating of 6,000 psig.

Relief Valves. Both the hydrazine tank and the nitrogen supply system are protected from overpressurization by Anderson-Greenwood Series 80 pressure relief valves. These valves are set to relieve pressures in excess of 400 psid for the hydrazine tank and 3,300 psid for the nitrogen supply system.

Check Valves. Kepner check valves are used in the liquid hydrazine, GN_2 purge, and heat exchanger lines to prevent flow reversals and/or fluid contamination. These valves are an in-line type machined from 303 stainless steel and have teflon seals.

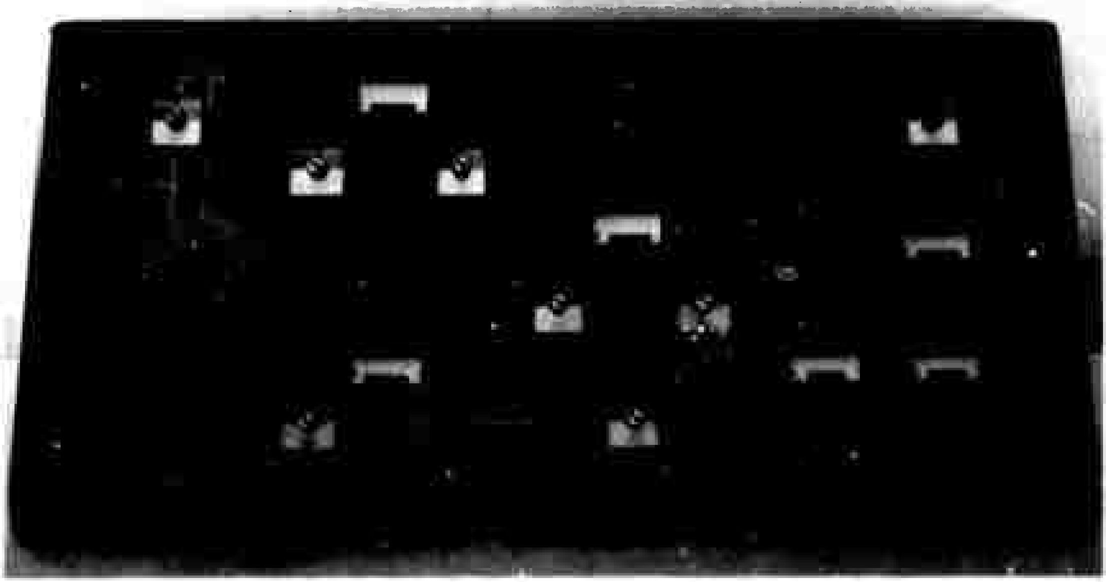

Figure 8. Operator's console for hydrazine gas-generation system.

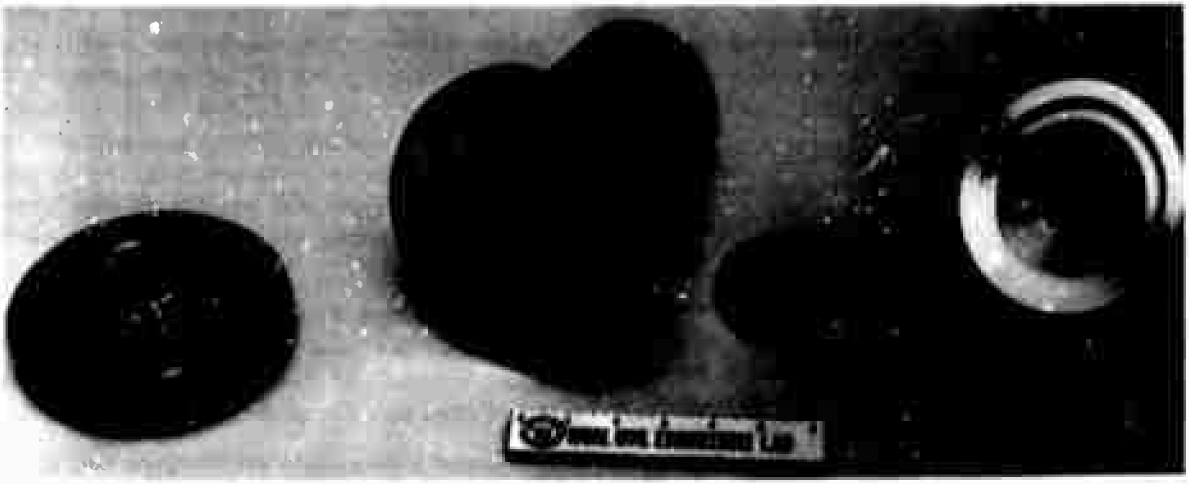

Figure 9. Monopropellant gas generator prior to assembly.

Pressure Regulators

The pressure regulators used to control the hydrazine tank pressure and the GN_2 purge pressure are Grove Model 15LX regulators equipped with Barber-Colman Model EYLC remote actuators. The regulators have an inlet pressure rating of 6,000 psig and an outlet pressure range of 0-300 psid. The regulators were fitted with protective polyvinyl chloride (PVC) sleeves to reduce contact with seawater spray and are the only components of the hydrazine system which will not operate when directly submerged in seawater.

Filters

Western in-line type filters are used in both the liquid hydrazine and GN_2 lines to remove particulate matter larger than 30 microns.

Piping System

A piping schematic of the hydrazine gas generation system is shown in Figure 11. The high pressure gaseous nitrogen flow system was assembled with 1/4-inch-OD by 0.049-inch-wall stainless steel tubing. The low pressure GN_2 flow system (less than 400 psid) and the liquid hydrazine flow system were assembled from 1/2-inch-OD by 0.035-inch-wall stainless steel tubing. All tube fittings and connections were standard AN 37-degree external flare type (MS33584).

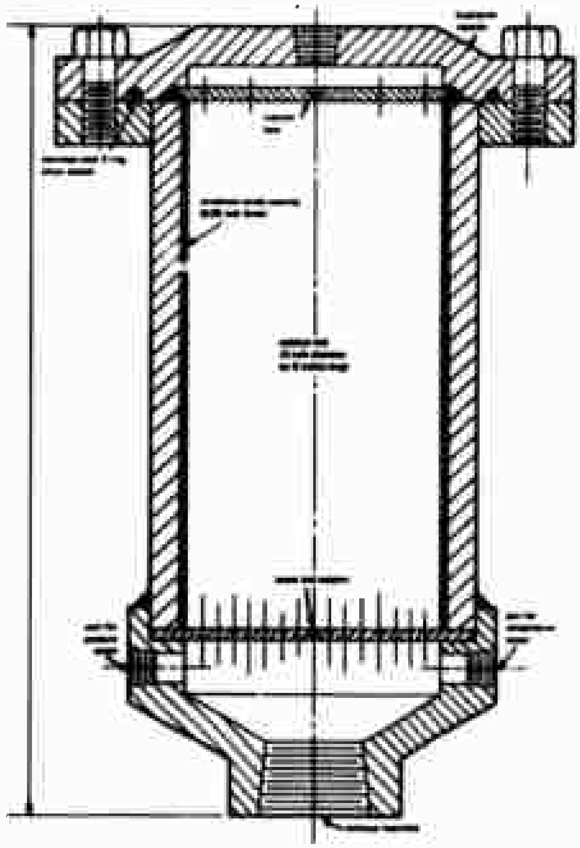

Figure 10. Cross-sectional drawing of monopropellant gas generator.

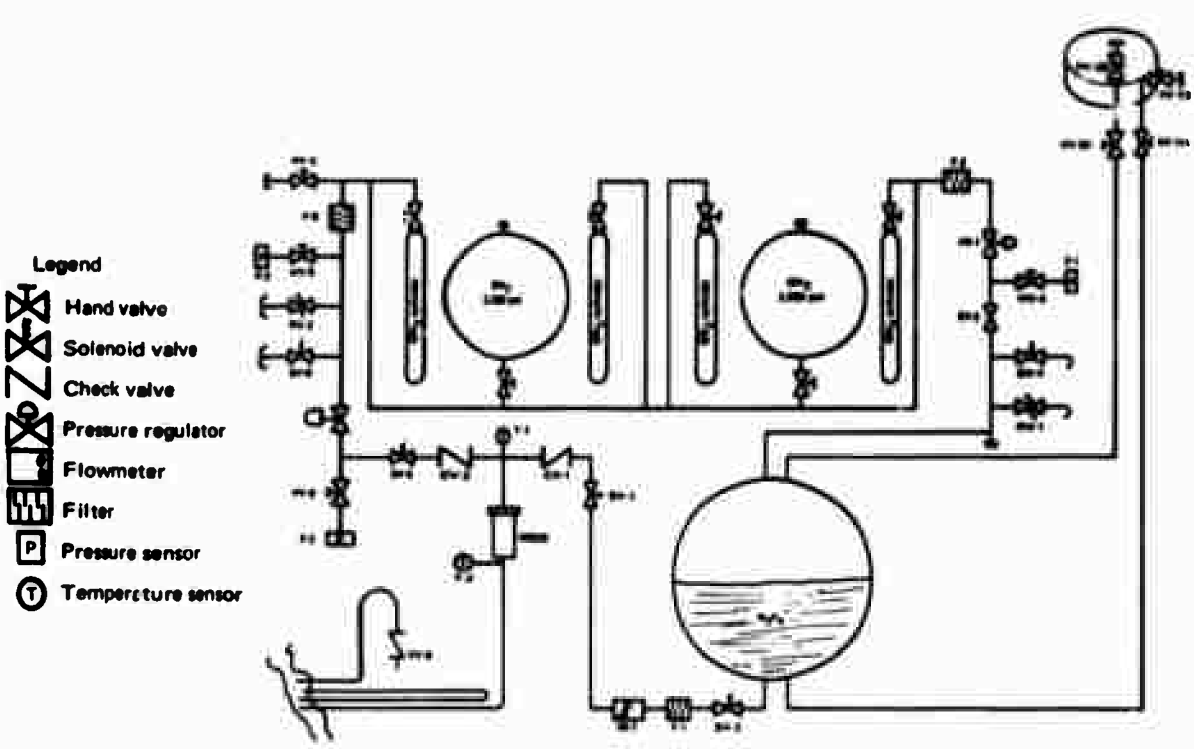

Figure 11. Piping schematic of the hydrazine gas-generation system.

Heat Exchanger

The heat exchanger is located directly under (exterior to) the pontoon. This heat exchanger is approximately 100 feet long and fabricated from sections of 1-inch schedule 40 stainless steel pipe welded together. Rollers are used to support the heat exchanger but allow movement due to thermal expansion. The inlet of the heat exchanger is welded directly into the MGG exhaust port. The exit of the heat exchanger is in the forward dry chamber; a check valve and gas diffuser are welded to the exit end.

Instrumentation

Pressure. Pressure measurements are made with Genisco Model PB427B bonded strain gage differential pressure transducers. The standard electrical connector for these transducers was replaced with a Kintec underwater pigtail connector sealed by a Conax PG packing gland and potted in RTV sealant.

Temperature. Temperature measurements are made with Rosemont Model 104MB platinum resistance type direct immersion transducers. The electrical ends of the transducers are fastened to electrical condulet boxes by Swagelok tube fittings. These boxes are also fitted with Kintec underwater bulkhead connectors potted in Type 1C Epoxi-Patch and small neoprene finger-shaped bladders. The condulet boxes are filled with silicone oil and the box covers sealed with a rubber O-ring.

Flowrate. The liquid hydrazine volumetric flowrate is measured with a Fischer-Porter Model 1/2-2 turbine-type flowmeter. The flowmeter pickup coil is mated to an electrical condulet box which is pressure compensated and identical to those used for the temperature transducers.

Electrical System

All instrumentation signal conditioning equipment, relays, etc., for the hydrazine system are contained in a water-tight, pressure-proof electrical junction box located inside the pontoon. A photograph of the equipment contained in this junction

box is shown in Figure 12. The junction box cover was drilled and tapped for Kintec underwater bulkhead connectors. A photograph of the forward junction box cover is shown in Figure 13. Underwater jumper cables are connected from this cover to the appropriate electrical components on the hydrazine system. Nylon straps are used to fasten the cables to the hydrazine frame.

Similar junction boxes are located in the other pontoon compartments and interconnected by pressure-proof conduit. A 47-conductor underwater cable and mating connectors are used to connect the pontoon to the operating consoles aboard the surface support craft.

HYDRAZINE SYSTEM DEVELOPMENT

Details of the development program relating to the hydrazine gas-generation system are contained in this section.

Monopropellant Gas Generator Design

Method of Hydrazine Decomposition. Liquid hydrazine can be decomposed either thermally or catalytically. Thermal decomposition of hydrazine is usually accomplished by passing hydrazine through a packed bed of metal shot or screens which has been heated to a high temperature (above 600°F). The catalytic decomposition of hydrazine uses either a spontaneous or nonspontaneous catalyst; both types are readily available. The differentiation between spontaneous and nonspontaneous catalysts is somewhat arbitrary. Generally, spontaneous catalysts will initiate hydrazine decomposition on contact while nonspontaneous catalysts must be heated to some minimum temperature (less than 600°F) before they will initiate and sustain decomposition.

Figure 12. Instrumentation signal conditioning equipment.

In the present application, the hydrazine gas-generation system requires rapid-start characteristics, long gas generation times (8 hrs total), and a multiple restart capability so that the buoyancy gas can be produced whenever needed. Hence, it was necessary to use a spontaneous catalyst to decompose the hydrazine. Previous studies on hydrazine catalysts [7-9], have shown Shell 405 catalyst to be the most reactive and durable spontaneous catalyst available; it was the catalyst selected for use in the present system.

Catalyst Bed Dimensions. The ability of a catalyst to decompose the hydrazine or ammonia into hydrogen and nitrogen gases is dependent on both the quantity of catalyst used and the length of time the propellant is in contact with the catalyst. RRC (Rocket Research Corporation) has developed a semi-empirical equation relating the fraction of ammonia dissociated (X) to significant operational variables for hydrazine decomposed by Shell 405 catalyst [10]. The RRC equation is:

$$\ln\left(\frac{1-0.5}{1-X}\right) = \left(\frac{152.5\,G^{0.71}\,t}{d_p^{0.32}\,\overline{P}}\right) \tag{3}$$

where X = fraction of ammonia dissociated

G = bed loading (liquid hydrazine flowrate per unit cross-sectional area of catalyst bed), lb/sec-in.^{2}

t = residence time in the catalyst bed, msec

d_p = average particle diameter, ft

P = mean bed pressure, psia

Note that the form of Equation 3 allows the fraction of ammonia dissociation to vary only between 0.5 and 1.0. For constant gas properties throughout the catalyst bed, and applying the perfect gas law, Equation 3 may be expressed as [5]:

$$\ln\left(\frac{1-0.5}{1-X}\right)(18.79 + 8.88\,X - 7.11\,X^2) = \frac{\epsilon L}{d_p^{0.32}\,G^{0.29}} \qquad (4)$$

where ϵ is the volume fraction of the bed unoccupied by catalyst and L is the catalyst bed length.

The most suitable catalyst particle size for the subject application is 1/8-inch-diameter by 1/8-inch-long cylindrical pellets. Values of void fraction and particle diameter for this size catalyst are reported in Reference 10 as a function of bed diameter.

The specified liquid hydrazine flowrate for the gas generation system is 800 gallons in 4 hours, or 0.233 lb/sec. Normally, bed loadings in the range of 0.008 to 0.08 lb/sec-in.^{2} are employed with Shell 405 catalyst. For this hydrazine flowrate and the normal range of bed loadings, the catalyst bed diameter could vary between 1.9 and 6.0 inches. In this study, a catalyst bed diameter of 3 inches and a consequent bed loading of 0.033 lb/sec-in.^{2} were selected.

Figure 13. Forward junction box cover showing underwater bulkhead connectors.

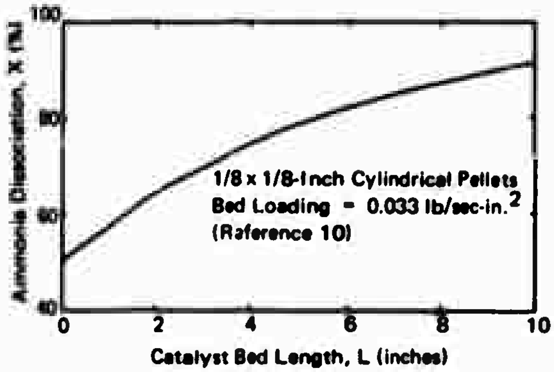

Figure 14. Variation of ammonia dissociation with catalyst bed length; Reference 10.

Figure 14 shows the variation of ammonia dissociation with bed length predicted by Equation 4, for a bed loading of 0.033 lb/sec-in.^{2} and 1/8-inch cylindrical catalyst pellets. From this figure it can be seen that a catalyst bed length of 6 inches is necessary to produce an ammonia dissociation level of 80%, and hence, was the bed length selected for the MGG.

Catalyst Bed Pressure Drop. To prevent crushing of catalyst particles, the catalyst bed pressure drops should not exceed certain limits, depending on the physical properties of the catalyst. Catalyst bed pressure drops as high as 75 psi have been used with Shell 405 without evidence of catalyst breakup, but bed pressure drops less than 40 psi are recommended [6].

Grant [4] developed the following equation for pressure drop across a catalyst bed:

$$\Delta P = 1{,}260\,\frac{A_s^{1.2}}{\epsilon^{1.7}}\left(\frac{G^{1.2}}{P}\right)$$

for $$100 < N_{Re} = 5.41 \times 10^5\,\frac{G}{A_s} < 600 \qquad (5)$$

where A_s is the catalyst specific surface area in the bed. This semi-empirical equation is based on constant property data for X = 0.5. The variation of catalyst bed pressure drop with bed exit pressure is shown in Figure 15 for the catalyst bed configuration employed in this study. From this figure it can be seen that the catalyst bed pressure drop is more than 100 psi at an exit pressure of 14.7 psia but decreases

to only 13 psi at an exit pressure of 500 psia. It should be recalled that the gas exhausts from the catalyst bed into a heat exchanger before being returned to the pontoon at the ambient seawater pressure. Hence, the pressure drop through the heat exchanger must be at least 130 psi at the ocean surface in order to maintain the catalyst bed pressure drop to an acceptable level.

Injector Design. The MGG injector is used to distribute the liquid hydrazine over the upstream surface of the catalyst bed and also to provide the upper bed support. The injector used in this program was a simple showerhead type. That is, a flat plate with orifices drilled normal to the plate face. Twenty-five orifices, or elements, 0.0210 inch in diameter, were used for this injector. The spacing of these orifices over the injector face is shown in Figure 9. The liquid manifold behind the injector face (Figure 10) provides cooling for the injector and minimizes heat transfer to the incoming liquid to prevent boiling of the hydrazine and possible detonation.

The pressure drop through the injector is governed by the standard orifice equation:

$$W = 0.525 N D^2 C_D \sqrt{\rho \Delta P} \tag{6}$$

where W = liquid flowrate, lb/sec

N = number of orifices

D = orifice diameter, in.

C_D = discharge coefficient

ρ = liquid density, lb/ft^3

ΔP = injector pressure drop, psi

The experimental discharge coefficient, C_D, was determined to be 0.65 by a series of water calibration flows. The results of the water calibration tests, that is, the variation of injector pressure drop with liquid flow, are shown in Figure 16. These tests were performed with deionized water but because the density of water and hydrazine are identical, the curve is applicable to either fluid. At the nominal hydrazine flowrate of 1.67 gal/min (0.233 lb/sec) the measured injector pressure drop is 60 psi. This degree of pressure drop aids in damping pressure and flow oscillations and accords smooth stable combustion.

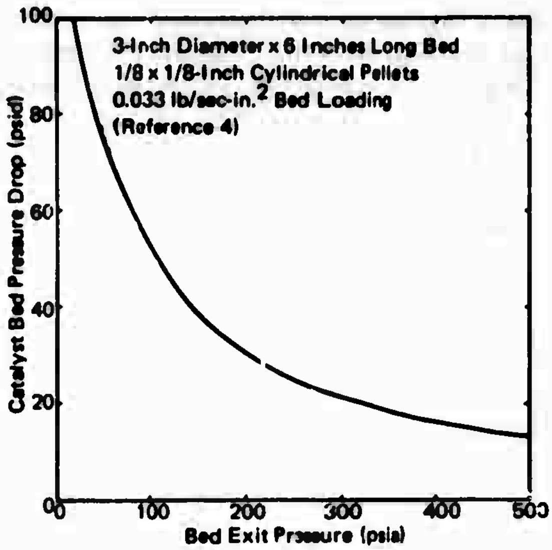

Figure 15. Variation of catalyst bed pressure drop with bed exit pressure; Reference 4.

Lower Bed Support. The lower bed support is used to retain the catalyst particles but allow passage of the exhaust gas. The initial lower bed support design consisted of 163 holes, 0.093 inch in diameter, drilled in a 1/8-inch-thick inconel 600 plate. The upstream and downstream edges of the holes were chamfered, 1/32 inch by 45 degrees, to minimize pressure drop. Inconel 600 was selected because of its high strength at elevated temperatures. The total open area of the support plate was 1.1 in.^{2}, 40% more than the heat exchanger cross-sectional area, to prevent the lower bed support from acting as a sonic nozzle.

During initial tests of the MGG, the lower bed support buckled and had to be replaced with a stronger one. The new lower bed support was 3/16-inch thick and contained only 149 holes. This modified bed support performed satisfactorily and no further difficulties with the lower bed support were encountered during the testing program.

Catalyst Bed Packing. The procedure for packing, or loading the catalyst, was to place approximately 1/6 of the catalyst in the MGG and then repeatedly tap the side of the reactor sharply with a small hammer, permitting the catalyst to settle in the bed. A second quantity of catalyst was then added and the process repeated. When the bed was

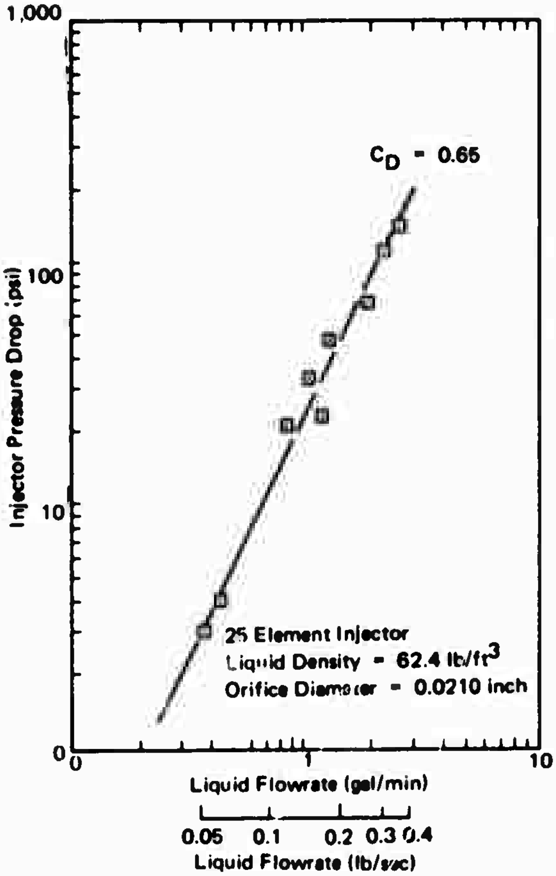

Figure 16. Variation of injector pressure drop with liquid flowrate.

completely filled, the injector was placed on top of the reactor and bolted into place. The MGG was then pressurized to 50 psig with nitrogen gas and checked for leaks.

Monopropellant Gas Generator Testing

First Test Series. Proper operation of the MGG is requisite to the hydrazine gas generation system in producing the required type and quantity of buoyancy gas to the LOSS pontoon. Hence, a series of MGG performance tests were conducted at the Skytop Test Facility, Naval Weapons Center, China Lake, California. The purpose of these tests was twofold; (1) to verify the ability of the MGG to initiate and sustain the smooth stable decomposition of hydrazine, and (2) to measure the degree of ammonia dissociation produced by the MGG.

A piping schematic of the flow system used in the MGG performance tests is shown in Figure 17. The MGG was packed with 2.156 pounds of catalyst by the method previously described and mounted to a support fixture located directly above a 220 gallon water bath. A heat exchanger fabricated from 1-inch-OD by 0.038-inch-wall stainless steel tubing, 40 feet long, was submerged in the water bath. Two sample bottles were located downstream of the heat exchanger. These sample bottles were remotely and independently operated to collect samples of the exhaust gas during a test. The gas samples were subsequently analyzed for ammonia dissociation by the Liquid Propellants Branch, NWC, using a gas chromatograph technique described in Reference 5. The exhaust gas line terminated with a 21/32-inch-diameter orifice used to increase the reaction pressure in the MGG.

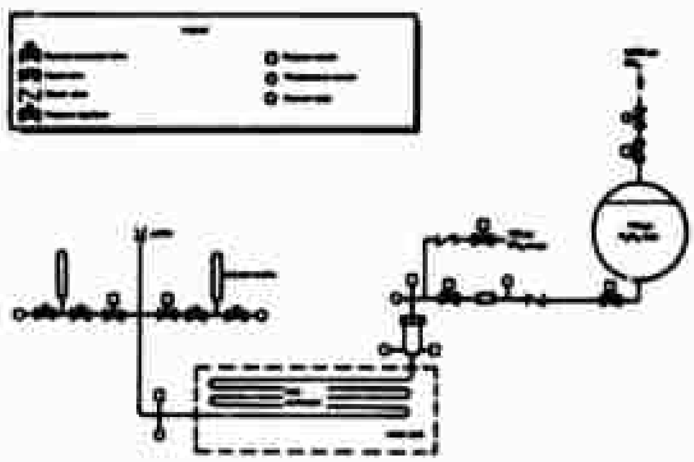

Figure 17. Piping schematic of flow system used in MGG performance tests.

A photograph of the MGG prior to testing is shown in Figure 18 and a photograph of the overall test setup is shown in Figure 19.

Three separate tests were made in this test series. The initial run was only 15 seconds duration and served to establish that initiation of hydrazine decomposition would occur. This test was quickly followed by a 40 minute test at the design hydrazine flowrate. After the second test, the MGG was allowed to cool down to ambient temperature. A third test identical to the second but only 12 minutes duration was then performed to verify the restart capability of the MGG. All three tests were completed without incident.

A summary of the flow conditions for each run is shown in Table 1. The hydrazine inlet pressure for Runs 2 and 3 are essentially identical but the flowrate for Run 3 is 9% lower and the catalyst bed pressure drop is 40% higher. A comparison of the injector and catalyst bed pressure drops for each of the three runs is shown in Table 2 along with the predicted catalyst bed pressure drop (Equation 5). From this table it can be seen that the predicted catalyst bed pressure drop is equal to the measured pressure drop for Run 2 but lower than the measured pressure drop for Run 3, indicating there was some compacting or settling of the catalyst between these two tests. An inspection of the catalyst bed after testing revealed that the bed had compacted approximately 1/4 inch and that 0.135 pound or 6.3% of the catalyst had been lost during these tests. However, the amount of broken or abraded catalyst was small and since some compacting and loss of catalyst is expected at these high pressure drops, this condition was considered acceptable.

One gas sample was collected during each of the last two runs. Unfortunately, the gas sample collected during Run 2 was exhausted before the analysis was completed. Analysis of the gas sample taken in the middle of Run 3, however, established the ammonia dissociation level at 90%, with a standard deviation of ±2%. Thus, it was demonstrated that the catalyst bed was operating very effectively and producing a high quality buoyancy gas.

Because the gas analysis method of determining ammonia dissociation is so time consuming, other

Figure 18. MGG prior to first test series at Skytop Test Facility, Naval Weapons Center, China Lake, CA.

Figure 19. Test setup for first test series at Skytop Test Facility, Naval Weapons Center, China Lake, CA.

Table 1. Summary of Flow Conditions for First Series of MGG Tests

Run Number	Run Duration (min)	N_2H_4 Flowrate (gal/min)	N_2H_4 Pressure to MGG (psia)	N_2H_4 Inlet Temperature to MGG (°F)	Exhaust Gas Pressure from MGG (psia)	Exhaust Gas Temperature from MGG (°F)	Heat Exchanger Exit Pressure (psia)	Remarks
1	0.25	0.87	114.5	55.5	56.5	1,339	–[a]	Ignition test
2	40.0	1.80	244.5	51.5	123.5	1,440	63.9	
3	12.0	1.63	243.5	44.0	105.5	1,430	56.5	Pressure drop across MGG has increased

[a] Not recorded.

Table 2. Comparison of MGG Pressure Drops for First Test Series

Run Number	Injector Pressure Drop (psid)	Catalyst Bed Pressure Drop (psid)	Predicted Catalyst Bed Pressure Drop [4] (psid)
1	17	41	–
2	69	52	52
3	61	73	47.2

methods are frequently employed. One common method, based on the thermochemistry of hydrazine decomposition, relates the adiabatic reaction temperature to the ammonia dissociation level [4]. A temperature sensor located at the exit of the catalyst bed is used to measure the adiabatic reaction temperature. Also, for a given catalyst bed configuration, Equation 4 can be used to estimate the ammonia dissociation level based on the hydrazine flowrate (the only unspecified flow parameter). A summary of these estimates for degree of ammonia dissociation during Runs 2 and 3 is shown in Table 3. Based on the temperature of the exhaust gas, the ammonia dissociation level is 76% for both runs. The semi-empirical equation (Equation 4) predicts ammonia dissociation levels of 82 and 83% for Run 2 and 3, respectively. Both techniques predict ammonia dissociation levels somewhat lower than the measured value.

During this test series the MGG was operated in an ambient air environment. This method of operation was selected to determine if the MGG could operate without any auxiliary method of cooling being supplied. A photograph of the MGG taken after the test series is shown in Figure 20. The central portion of the reactor body was oxidized and discolored but had not sustained any structural damage. The flange of the reactor and the injector still appeared new and bright, indicating that the liquid hydrazine flowing through the injector had provided cooling to these areas. The condition of the injector body is shown more clearly in Figure 21.

An inspection of the interior of the MGG showed no evidence of distortion or damage, with the exception of the lower bed support. This support had buckled or bowed into a dish shape, approximately 1/8 inch deep. The bed support design was modified slightly and the thickness increased 50%, from 1/8 inch to 3/16 inch, for all future tests.

A thermocouple was located in the exhaust gas line downstream of the heat exchanger to measure the exiting gas temperature. This temperature was a consistent 60°F higher than the bulk water bath temperature. Hence, it was concluded that the proposed pontoon heat exchanger consisting of 100-foot-long, 1-inch-diameter schedule 40 stainless steel pipe would be more than adequate in delivering the buoyancy gas back to the pontoon at ambient temperature.

In summary, the design of the MGG had proved entirely satisfactory. The MGG operation was smooth and stable and the level of ammonia dissociation was

higher than expected. The MGG operated without any additional cooling being supplied and only a moderate-length heat exchanger was required to cool the gas down to ambient temperature.

Table 3. Comparison of Estimates for Degree of Ammonia Dissociatiun—First Test Series

Run Number	Ammonia Dissociation, X (%)		
	By Gas Analysis	By Temperature Measurement (R4)	By Semi-Empirical Equation 5 (R10)
2	a	76	82
3	90	76	83

[a] Sample exhausted before analysis was completed.

Second Test Series. Shortly after the first test series had been completed, the LOSS Demonstration Plan was revised to include only a shallow water (100 feet) demonstration of the hydrazine system. Because of the shallow depth, and a very low proposed rate of descent, the required rate of buoyancy gas generation was decreased by almost 50%. Hence, it was decided to conduct a second series of MGG tests, similar to the first series but at approximately one-half the original hydrazine flowrate. The test setup for this series of tests was virtually the same as for the previous series, with one exception; the MGG was submerged in the water bath. A photograph of the MGG mounted to a support fixture in the water bath is shown in Figure 22. A photograph of the overall test setup is shown in Figure 23.

Two runs were scheduled for this test series. One was a long duration (100-minute) run to verify the steady state operation of the reactor and the second was a shorter (10-minute) run to verify the restart capability of the MGG. The nominal hydrazine flowrate for both runs was to be 0.9 gal/min.

The first run was initiated at a low hydrazine flowrate (0.42 gal/min) and after approximately one minute of operation the flowrate was increased to slightly more than the nominal value (0.95 gal/min). However, as soon as the flowrate was increased, the combustion became very unstable as evidenced by severe flow and pressure oscillations in the reactor. The MGG was allowed to operate with this unstable flow condition in order to determine if the flow oscillations would damp out with time. Also, it was desirable to know if the MGG could sustain unstable combustion without a structural failure. After an additional 12 minutes of operation, during which time no change was observed in either the frequency or magnitude of oscillations, the hydrazine flowrate was increased to 1.25 gal/min. The combustion remained very unstable and three minutes later this run was terminated. A summary of the averaged flow conditions for the three parts of this run (4A, 4B, and 4C) are shown in Table 4.

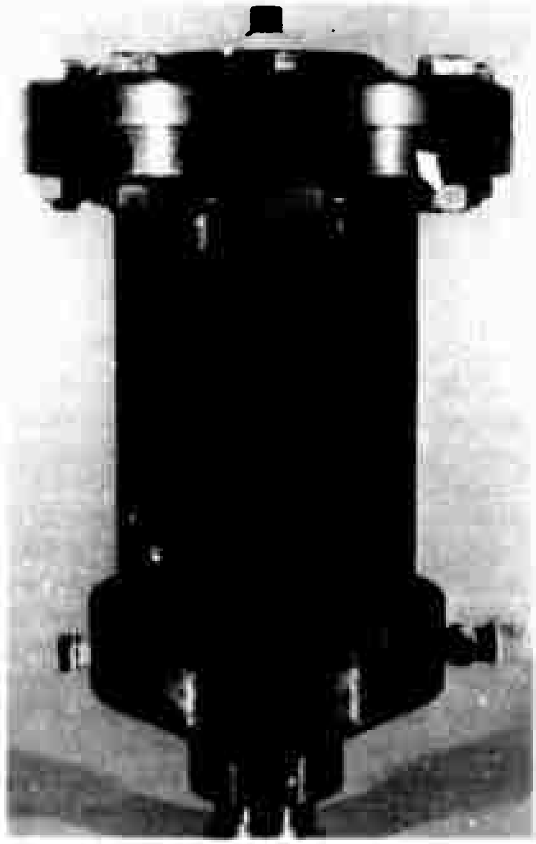

Figure 20. MGG after first test series—discoloration due to high temperature.

Figure 21. Injector body after first test series–no discoloration from high temperature.

Figure 22. MGG prior to second test series at Skytop Facility, Naval Weapons Center, China Lake, CA.

During Run 4C, the peak-to-peak pressure oscillations in the hydrazine injector manifold were 138 psi with a frequency of 2.5 cycles per second. The hydrazine flowrate was recorded only every 3.6 seconds, hence it was not possible to determine the instantaneous hydrazine flow variations. An indication of the magnitude of the flow oscillations, however, is given in Figure 24. This figure shows the hydrazine flowrate versus time output of the digitized data acquisition system used to record most of the flow parameters.

After the MGG had cooled to ambient temperature, it was removed from the test fixture and inspected for damage. The injector was also removed from the reactor body. Both the interior and exterior of the MGG appeared in good condition. The catalyst bed had settled approximately 1/4 inch, but the catalyst particles at the upstream end of the bed were in good condition. New catalyst was used to replenish the bed. The injector was bolted back on the reactor body and the MGG was reinstalled in the test fixture.

It was concluded that the low flowrate and low reaction pressure were causing a low injector pressure drop but a high catalyst bed pressure drop and this combination of pressure drops was promoting the combustion instability. To alleviate this problem, the 21/32-inch-diameter orifice in the exhaust gas line was replaced with a 21/64-inch-diameter one. This smaller diameter orifice would increase the reaction pressure, and thus, decrease the catalyst bed pressure drop; the injector (liquid) pressure drop would not be affected.

The second run was initiated at a liquid flowrate of 0.70 gal/min. The flow and pressure oscillations had been considerably damped by the smaller diameter orifice but were still present. The peak-to-peak pressure oscillations in the injector manifold were only 40 psi but the frequency had increased to 15.5 cycles per second. Flow oscillations were also reduced, as evidenced by the hydrazine flowrate versus time trace of the digitized data system, Figure 25.

After three minutes of operation, the hydrazine flowrate was increased to 0.88 gal/min. No changes were observed in the degree of combustion stability. The MGG operated at these conditions for an additional 42 minutes without change. Finally, the liquid flowrate was increased to 1.10 gal/min. At this

flowrate the flow and pressure oscillations were observed to increase slightly and nine minutes later this run was also terminated. A summary of the averaged flow conditions for the three parts of this run (5A, 5B, and 5C) are shown in Table 4.

A post-test inspection of the catalyst bed found the bed to be full and tight against the injector face. No further settling had occurred after the bed was repacked between Runs 4 and 5. However, approximately 1/2 inch to 2-1/2 inches below the injector face, the catalyst was badly damaged and caked in place. In this region, many fines (very small catalyst particles) as well as cracked and broken catalyst pellets were evident. The remainder of the catalyst bed was in good condition. Because of the unknown quantity of catalyst added between tests, it was not possible to determine exactly how much catalyst was lost during these tests.

A comparison of the average injector and catalyst bed pressure drops for Runs 4 and 5 is given in Table 5. The average injector pressure drops were quite low, ranging from 4 to 34 psi, but the catalyst bed pressure drops were extremely high, 72 to 131 psi. Also, the unstable combustion created instantaneous pressure drops which were considerably different from the average values shown in Table 5.

A summary of the estimates for degree of ammonia dissociation during Runs 4 and 5 is shown in Table 6. From the temperature measurement of the MGG exhaust gas, ammonia dissociation levels were estimated to vary between 79 and 87%. The semi-empirical equation (Equation 4) predicted dissociation levels slightly higher, 84 to 90%. Four gas samples were analyzed from these two runs. Ammonia dissociation levels between 83 and 94% were obtained by this method.

Table 4. Summary of Flow Conditions[a] for Second Series of MGG Tests

Run Number	Run Duration (min)	N_2H_4 Flowrate (gal/min)	N_2H_4 Inlet Pressure to MGG (psia)	N_2H_4 Inlet Temperature to MGG (°F)	Exhaust Gas Pressure from MGG (psia)	Exhaust Gas Temperature from MGG (°F)	Heat Exchanger Exit Pressure (psia)	Remarks
4A	1.0	0.42	121.5	77	28.5	1,388	16.5	Stable combustion
4B	12.0	0.95	170.5	97	35.5	1,284	20.5	Unstable combustion
4C	3.0	1.25	211.5	93	46.5	1,324	24.5	Unstable combustion
5A	3.0	0.70	175.3	86	91.8	1,320	84.6	Unstable combustion
5B	42.0	0.88	212.0	85	114.3	1,345	106.3	Unstable combustion
5C	9.0	1.10	253.5	87	145.6	1,396	133.1	Unstable combustion

[a] All parameters averaged over 30 second interval.

Table 5. Comparison of MGG Pressure Drops for Second Test Series.

Run Number	Injector[a] Pressure Drop (psid)	Catalyst Bed[a] Pressure Drop (psid)
4A	4	89
4B	20	115
4C	34	131
5A	11	72
5B	17	81
5C	26	82

[a] Averaged over a 30 second interval.

From this test series it was concluded that: (a) the injector pressure drop would have to be increased to produce stable combustion at low flowrates, (b) sufficiently high ammonia dissociation levels were obtained, and (c) the MGG shell could sustain severe pressure oscillations without deleterious effects, but the catalyst bed could not.

Rather than conduct additional tests with the MGG separately, it was decided to complete the development of the hydrazine feed system, and the modifications required for the MGG, and conduct future tests with the complete system.

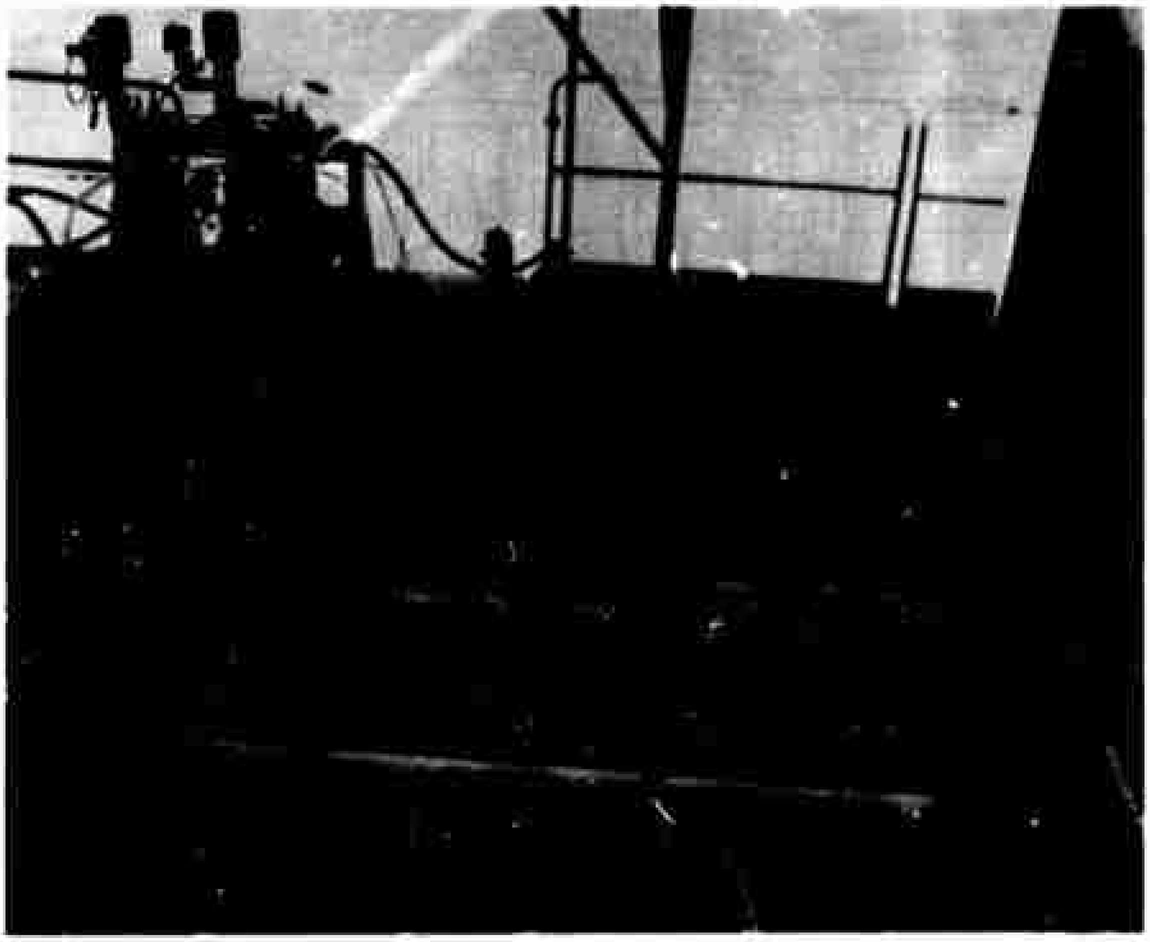

Figure 23. Test setup for second test at Skytop Test Facility, Naval Weapons Center, China Lake, CA.

Hydrazine Feed System

Two different feed system designs were initially considered: (1) a pump fed system, and (2) a pressure fed system. The pump fed approach offered the advantage of a much simpler and lighter weight system but would require critical by-pass circuits to maintain pressure equalization between the hydrazine tank and the seawater over the entire depth range (0-850 feet). On the other hand, the principal of operation of a pressure fed system is to compare the internal system pressure with the external system (seawater) pressure; that is, changes in depth are automatically compensated for. Also, the pressure fed system is more flexible and easily adaptable to changes in program requirements, not being limited by the design of one single expensive component (the pump/motor). Hence, the pressure fed approach was selected as most prudent for the subject application.

The components used in the feed system were described earlier in this report. With the exception of the solenoid valves, all components were off-the-shelf purchases, modified in some instances to permit operation in an underwater environment. The solenoid valves were a special purchase due to the high pressure housing required for the coil. No difficulty was encountered in employing any of these components in the manner described herein.

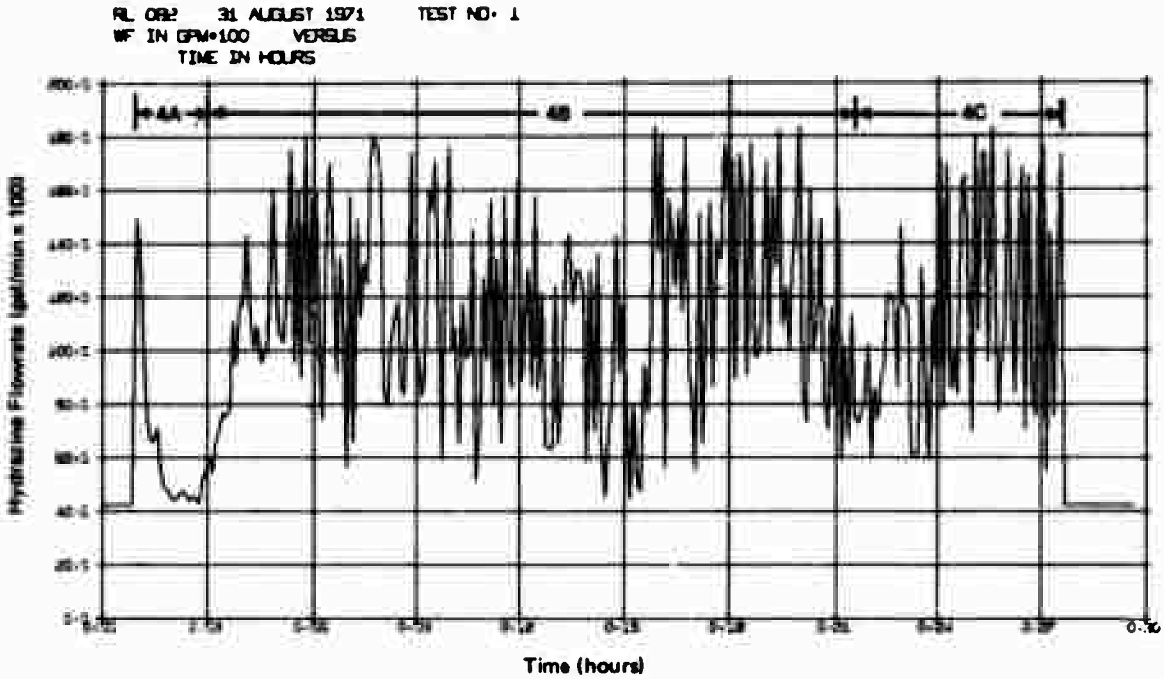

Figure 24. Liquid hydrazine flowrate versus time; output from digitized data acquisition system for Run 4.

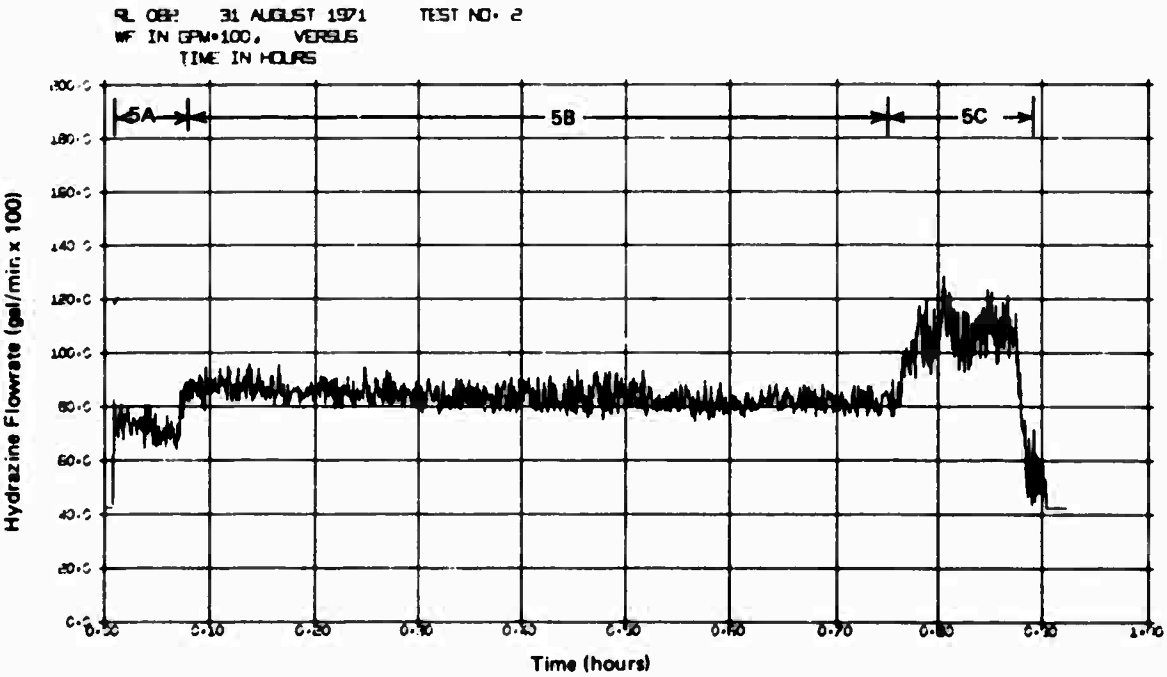

Figure 25. Liquid hydrazine flowrate versus time; output from digitized data acquisition system for Run 5.

Table 6. Comparison of Estimates for Degree of Ammonia Dissociation–Second Test Series

Run Number	Ammonia Dissociation (%)		
	By Gas Analysis	By Temperature Measurement[a] (4)	By Semi-Empirical Equation 5[a] (10)
4A	–	80	90
4B	94	87	86
4C	89	84	84
5A	–	85	87
5B	83	83	86
5C	85	79	85

[a] Based on averaged flow conditions.

Operating and Checkout Procedures

Procedures for operating and checking the system were developed concurrently with the fabrication of the gas generation system. These procedures, in the form of checklists, were used to ensure the safe and proper operation of the system.

System Checkout. A thorough checkout of the system is performed just before the system is filled with gaseous nitrogen and hydrazine. The purpose of this procedure is to verify that (a) all electrical leads are properly installed, (b) all components (both manual and electrical) function properly, and (c) the entire system is free from leaks. The checklist for this system checkout procedure is contained in Appendix B.

Charging GN_2 System. The GN_2 system is charged from commercially available 6,000-psi nitrogen cylinders. The GN_2 is transferred, or cascaded, from a 6,000-psi cylinder into the system. Approximately fourteen 6,000-psi cylinders are required to completely charge the GN_2 system. The checklist for charging the GN_2 system is contained in Appendix C.

Hydrazine Tanking. Liquid hydrazine is procured from the Air Force in 55-gallon stainless steel drums. The required quantity of hydrazine is transferred from the drum to the hydrazine tank by means of a vacuum, initially drawn on the hydrazine tank, and a slight pressurization (4 psi) of the drum. This technique requires approximately one hour to transfer 55 gallons of hydrazine. The personnel involved in the transfer operation are protected with rubberized coveralls, boots, gloves, and faceshields impervious to liquid hydrazine. The checklist for the hydrazine tanking procedure is contained in Appendix D.

Console Operation. A final verification of the system is performed by the console operator just before initiating hydrazine flow. Then, depending on the nature of the test, the console operator initiates the hydrazine flow, monitors and adjusts system performance, and when test objectives have been reached, secures the system. The console operator's checklist for an in situ test is contained in Appendix A.

Hydrazine De-Tanking. If for any reason it becomes necessary to transfer the liquid hydrazine back into the 55-gallon drums, a hydrazine de-tanking procedure must be followed. The hydrazine de-tanking checklist, which is essentially the reverse of the tanking procedure, is contained in Appendix E.

System Testing

The final step in the hydrazine system development program was a series of surface performance tests of the completed gas generation system. The objectives of these tests were: (1) to ensure that modifications made to the MGG following the second test series were sufficient for stable operation at low hydrazine flowrates, (2) to verify that the system and its components (feed system, operator's console, etc.) would operate satisfactorily, and (3) to provide a full rehearsal for the operating personnel in the step-by-step operation of the system.

Monopropellant Gas Generator. Two modifications were made to the MGG for this test series. The injector orifice diameter was reduced from 0.0210 inch to 0.0156 inch, and the catalyst bed length was reduced from 6 inches to approximately 4-1/4 inches with a 1-3/4-inch thermal bed added.

Decreasing the injector orifice diameter increases the pressure drop across the injector, thereby reducing the possibility of combustion instability.

The variation of injector pressure drop with liquid flowrate is shown in Figure 26 for both the small and large orifice injectors. At he low hydrazine flowrate (0.9 gal/min), the large orifice injector pressure drop is only 17 psi. At this same flowrate, the new, small orific injector pressure drop is 60 psi.

In the previous two MGG test series, the catalyst bed pressure drop was consistently higher than the 40 psi recommended value. To reduce the catalyst bed pressure drop and thus conserve catalyst, the downstream portion of the bed volume was filled with 1/8-inch-diameter stainless steel shot. This thermal bed was approximately 1-3/4 inch long. The remaining 4-1/4 inches of the bed was packed with shell 405 catalyst in the normal manner. Two 20-mesh stainless steel screens were placed between the lower bed support and the stainless steel shot to prevent the spherical shot from blocking the holes in the bed support.

Experimental Facility. This test series was conducted at the Horizontal Firing Bay of the Naval Missile Center (NMC), Point Mugu, California. A photograph of the hydrazine system in the Firing Bay at NMC is shown in Figure 27. A large portable swimming pool, 12 feet in diameter by 3 feet deep, shown in the foreground of Figure 27 was used as a water bath for the heat exchanger. The heat exchanger used in this test series was fabricated by NCSL and was a close facsimile of the heat exchanger located under the LOSS pontoon. This heat exchanger was fabricated from 1-inch-diameter, schedule 40, stainless steel pipe, 100 feet long. End connections are ASA flanges sealed with Flexatallic spiral-wound gaskets containing a teflon-impregnated asbestos filler. A photograph of this heat exchanger is shown in Figure 28.

The MGG was packed with 1.615 pounds of catalyst and 2.081 pounds of stainless steel shot and mounted at its normal location in the hydrazine system. Approximately 15 feet of 1-inch-diameter, stainless steel tubing connected the MGG and the heat exchanger. A photograph of the MGG mounted in the hydrazine system is shown in Figure 29. A low pressure water spray, seen just to the right of the MGG, was used to cool the exterior of the MGG during testing.

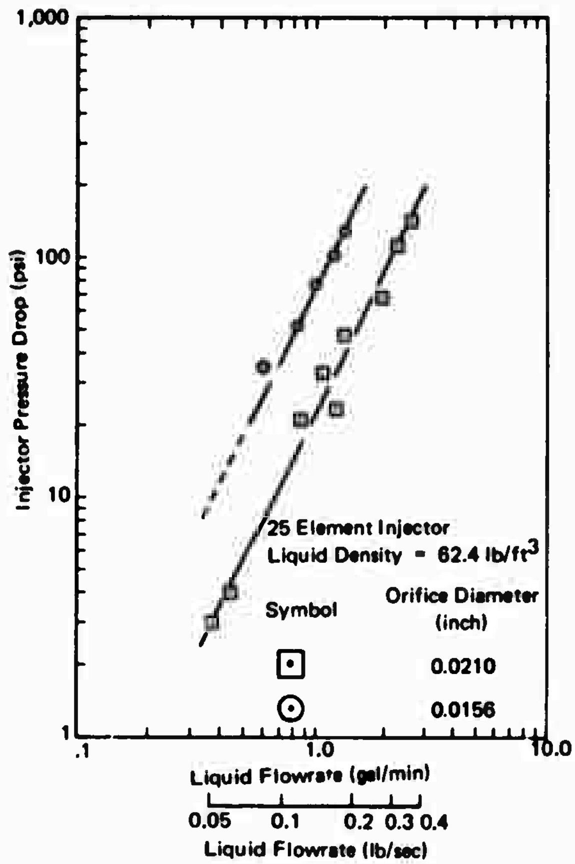

Figure 26. Variation of injector pressure drop with liquid flowrate for both the small and large orifice injectors.

Test Preparations. The nitrogen system was charged to 3,000 psi with GN_2 following the procedure listed in Appendix C. The GN_2 was left in the nitrogen tanks for 24 hours and then the GN_2 system was inspected for leaks. No leaks were found, and subsequently, 55 gallons of hydrazine were transferred into the hydrazine tank following the procedure listed in Appendix D. The hydrazine was also left in the system for 24 hours, and the system was then visually inspected for leaks or signs of incompatibility between the hydrazine and its containment. No leaks were found and system testing was initiated shortly.

The operator's console was located in the test bay blockhouse, approximately 500 feet from the system. Electrical connections between the console and the hydrazine system were made via electrical cables organic to the test facility. A closed circuit television camera, located a short distance from the hydrazine system, was used to visually monitor the MGG during testing.

Test Results. The first test was conducted at a low hydrazine flowrate (0.32 gal/min), to verify that the system was operating properly. The run duration was 8 minutes and combustion was smooth and stable. The MGG was cooled to ambient temperature and a second test conducted. This test was initiated at a hydrazine flowrate of 0.68 gal/min but the hydrazine feed pressure, and hence the hydrazine flowrate, were slowly increased during the run. The run duration was 28 minutes and the hydrazine flowrate at the end of the run was 0.88 gal/min. Again, combustion was stable and all flow parameters were at the expected values. The MGG was cooled back to ambient temperature and a third test conducted to expend the remaining hydrazine. The feed pressure for the third run was again slowly increased during this 23-minute run and the hydrazine flowrate increased from 1.08 gal/min to 1.12 gal/min during the test. As before, performance was smooth and stable during the entire run. A summary of the flow conditions for this test series is contained in Table 7.

Figure 28. Heat exchanger and water bath used during system testing at Horizontal Firing Bay, Naval Missile Center, Pt. Mugu, CA.

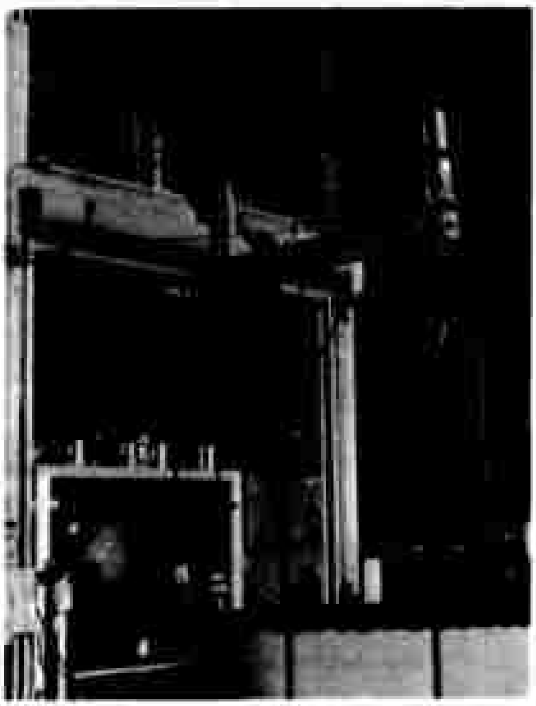

Figure 27. Hydrazine gas-generation system prior to system testing at Horizontal Firing Bay, Naval Missile Center, Pt. Mugu, CA.

A post-test inspection of the catalyst bed found the catalyst to be in excellent condition. The catalyst bed pressure drop had been less than 30 psi during these tests and the number of broken catalyst particles was very small. The bed had compacted approximately 1/4 inch, and there was evidence of abrasion on many of the catalyst particles. A total of 0.109 pound or 6.7% of the catalyst was lost during these tests.

Two gas samples were taken during Run 8, but the sample bottles had not been properly evacuated, and an adequate analysis by the Liquid Propellants Branch, NWC, was not possible. Based on the temperature of the exhaust gas leaving the MGG, however, the ammonia dissociation level was estimated to be

Figure 29. **MGG mounted in hydrazine system prior to system testing at Horizontal Firing Bay, Naval Missile Center, Pt. Mugu, CA.**

75 to 80% for a liquid hydrazine flowrate of 0.9 gal/min. This dissociation level was more than adequate for the shallow water (low pressure) demonstration of the system, hence, the combination catalyst/thermal bed configuration was retained for the forthcoming in situ test.

The bolts securing the inlet flange to the heat exchanger had loosened during the tests. It was believed that the alternate heating and cooling of the heat exchanger during testing caused these bolts to loosen; the bolts securing the exit (low temperature) flange had remained tight. These flanges were subsequently eliminated from the pontoon heat exchanger design and an all welded design was used.

The temperature of the gas leaving the heat exchanger was to be measured with a thermocouple The electrical leads for this thermocouple were improperly connected to the recording equipment, and hence no useful data were recorded for this temperature. It may be safely concluded, however, that based on previous heat exchanger temperature measurements, the temperature of the gas leaving the heat exchanger was essentially ambient.

In summary, the hydrazine system had proved satisfactory in producing a suitable buoyancy gas at the specified conditions and consequently was ready for the in situ test.

IN SITU TEST

Background

The LOSS demonstration test program is divided into three phases:

Phase I—Capability demonstration of the basic LOSS pontoon using compressed air from the surface for deballasting.

Phase II—Capability demonstration of two completely self-contained deballasting systems; liquid nitrogen and hydrazine.

Phase III—Capability demonstration of fixed orientation thrusters for pontoon maneuvering.

Phase I of the test program was conducted during September-October 1971 at a depth of 105 feet, in the waters off Panama City, Florida (Longitude 85°54'W, Latitude 30°N). A very detailed account of the Phase I operation is presented in Reference 11.

Phase III of the test program is currently being conducted and is scheduled to be completed in July 1973.

The hydrazine demonstration test, conducted as part of Phase II in July 1972, is described in the following section.

Hydrazine Demonstration Test

Immediately following the system tests at NMC, the hydrazine system was shipped to NCSL, Panama City, Florida for installation in the forward chamber of the pontoon. The installation of the liquid nitrogen system in the aft chamber of the pontoon was already underway.

At deep depths two liquid nitrogen systems, one in each end of the pontoon, are required to achieve maximum lift. However, because of the shallow depth

of the demonstration, only one LN_2 system was required. Also, since the pontoon was not maneuverable at this point and required considerable surface and diver support, the hydrazine system was used in conjunction with the LN_2 system to simplify at-sea handling of the pontoon during periods when hydrogen gas was present in the pontoon. The Phase II test site had been moved approximately 3 miles closer to shore than the Phase I test site. The water depth at this test site was 90 feet, as compared to 105 feet during the Phase I operation. This shallower depth was selected to provide the Navy divers more bottom time in which to complete their tasks. Limited diving time had been a particular problem during the Phase I tests.

The main surface support craft for the sea operation was the medium salvage lift craft, Windlass, (YMLC-4). A photograph of the YMLC is shown in Figure 30. The YMLC was towed to the test site and moored in place several days before the start of the Phase II Operation. Likewise, the salvage object, shown in Figure 31, was rigged with sixteen 8.4-ton inflatable pontoons and towed under the bow horns of the YMLC. Nylon lowering lines and six of the inflatable pontoons were used to lower the object to the bottom, directly under the bow horns of the YMLC.

Phase II was initiated with a demonstration of the LN_2 deballasting system. This demonstration was very successful and is being documented in a separate NAVSHIPS report.

The pontoon was returned to port after the LN_2 demonstration test and berthed at an isolated section of the NCSL dock area. The pontoon was given a thorough visual inspection, both internally and externally, and found to be in excellent condition. A complete checkout of the hydrazine system was also performed following the checkout procedure listed in Appendix B. A small portable N_2H_4 console was used in this checkout in lieu of the regular console which was still aboard the YMLC. During the checkout a high electrical contact resistance was found in two electrical cables; they were replaced with backup cables. Otherwise, the checkout was completed without incident. The forward pontoon chamber was then partially filled with fresh water. The water level was at the mid-point of the MGG reactor body. This water would provide cooling to the MGG and dilute any hydrazine leakage.

The nitrogen pressurization system was charged to 3,300 psig with GN_2 using the charging procedure listed in Appendix C. Access to the GN_2 fill valve was attained through the manway at the top of the forward compartment. After the nitrogen system was charged, this manway was sealed and bolted shut. The hydrazine tank would be filled by means of two protected hand valves located adjacent to the manway.

The LN_2 system was also checked, and refilled with liquid nitrogen. The manway at the top of this compartment was then sealed and bolted shut, after which a vacuum was pulled on all three pontoon compartments using a large steam ejector. The vacuum was relieved with gaseous nitrogen from the LN_2 system, thus providing a nonflammable atmosphere inside the pontoon.

Table 7. Summary of Flow Conditions for System Tests of the Hydrazine Gas-Generation System

Run Number	Run Duration (min)	N_2H_4 Flowrate (gal/min)	N_2H_4 Inlet Pressure (psia)	N_2H_4 Inlet Temperature (°F)	Exhaust Gas Pressure (psia)	Exhaust Gas Temperature (°F)	Remarks
6	8	0.32	64	62	44	1,400	
7[a]	28	0.68-0.88	129-164	65-68	64-84	1,500-1,550	Feed pressure was increased during run.
8[a]	23	1.08-1.12	199-205	70-72	94-94	–[b]	Feed pressure was increased during run.

[a] Both initial and final flow conditions shown.
[b] Faulty electrical connection on temperature sensor.

Figure 30. Surface support craft, Windlass, YMLC-4.

The dock area around the pontoon was then roped off in preparation for the hydrazine tanking. A photograph of the pontoon just prior to the tanking is shown in Figure 32. The platform scale, barely visible on the left side, was used to weigh the N_2H_4 drums and monitor the transfer rate. The small table contained wrenches and fittings to make the necessary plumbing connections. Two 55-gallon drums of hydrazine were transferred using the Dockside N_2H_4 Tanking Procedure (Appendix D). The entire fueling operation took just under four hours.

The following morning the pontoon was towed to the test site and positioned under the YMLC bow horns. A photograph of the pontoon ready for lowering is shown in Figure 33. Because of the close proximity of the pontoon and YMLC during the descent of the pontoon, the LN_2 system was used to provide the necessary buoyancy gas during lowering. This was done merely as a safety precaution against possible leaking hydrogen gas being present near the surface support craft.

The descent of the pontoon and attachment to the object were completed without incident. The YMLC moved back approximately 300 feet in the moor and a final checkout of the hydrazine system was performed, following the Console Operator Checklist (Appendix A). The hydrazine tank was pressurized to 170 psid and the hydrazine flow initiated. The reactor startup was smooth and rapid. The initial flowrate was 0.95 gal/min and very steady. After a few minutes of operation, the flowrate was increased to a final value of 1.26 gal/min. A check on the decomposition efficiency of the hydrazine was made based on the change of water level in the pontoon. Fifty L tons of water were displaced by decomposing 39 gallons of hydrazine. This corresponds to an ammonia dissociation level of approximately 82%. De-watering of the pontoon was completed in less than an hour. The remaining hydrazine was reacted and vented through the pontoon standpipe before the pontoon/object ascent was initiated. The ascent portion of the operation was completed without incident. A photograph of the pontoon venting hydrogen gas at the surface is shown in Figure 34. The white clouds are caused by water being entrained in the venting gas.

Several gas changes were made in the pontoon using the LN_2 system. These gas changes successively diluted the hydrogen gas concentration in the pontoon to a very low level. The pontoon was brought back under the YMLC bow horns; uncoupled from the object, and towed into port.

Figure 31. Salvage object.

Figure 32. LOSS pontoon prior to hydrazine tanking.

Figure 33. LOSS pontoon under bow horns of YMLC.

A photograph of the hydrazine gas generation system after the in situ test is shown in Figure 35. The system was still in excellent condition. Some minor corrosion was evident due to the partial submersion in water, but the operability and structural integrity of the system were unaffected.

The system had performed flawlessly during the in situ test. The performance and operating characteristics of the system had been identical to those observed during the previous system tests. In short, the hydrazine system has been demonstrated to operate as well in an underwater environment as in an air environment.

CONCLUSIONS

1. The catalytic decomposition of monopropellant hydrazine is a very effective technique for producing buoyancy in large salvage operations.

2. The handling of large quantities of liquid hydrazine, and its flammable decomposition products, can be conducted in real salvage operations with adequate safety precautions.

RECOMMENDATIONS

1. Serious attention should now be given to the utilization of hydrazine produced buoyancy gas in deep ocean salvage and/or recovery systems. It is at these deep depths that a low molecular weight buoyancy gas is most beneficial.

Figure 34. LOSS pontoon venting hydrogen gas after hydrazine demonstration test.

Figure 35. Hydrazine system after in situ test.

Appendix A

CONSOLE OPERATOR'S CHECKLIST[c]

I. Preliminary

_________ A. Verify from On-Scene Commander that all personnel are at their assigned stations and well clear of pontoon.

_________ B. Obtain permission from On-Scene Commander to energize console.

_________ C. Verify that 110VAC power supply is on and operating.

_________ D. Energize instrumentation main power.

_________ E. Verify that the following switches are in the closed (off) position:

- _______ 1. N_2H_4 main valve (SV-1)
- _______ 2. N_2H_4 shutoff valve (SV-2)
- _______ 3. N_2H_4 pressurizing valve (SV-3)
- _______ 4. N_2H_4 vent valve (SV-4)
- _______ 5. GN_2 purge valve (SV-5)
- _______ 6. GN_2 vent valve (SV-6)
- _______ 7. N_2H_4 pressure regulator (PR-1)
- _______ 8. GN_2 purge regulator (PR-2)

_________ F. Energize main console power.

- _______ 1. Verify that +28VDC power supply is on and operating.
- _______ 2. Verify that -28VDC power supply is on and operating.

II. Instrumentation System Checkout

After instrumentation power has been on for at least 10 minutes, check the following readings:

[c] See Figure 11 for schematic and component designations.

__________ A. GN_2 supply pressure (P-2) = 3000 psid min.

__________ B. N_2H_4 tank pressure (P-1) = 50 psid max.

__________ C. GN_2 purge pressure (P-3) = 50 psid max.

__________ D. N_2H_4 flowrate (W-1) = zero

__________ E. N_2H_4 inlet temperature (T-1) = ambient

__________ F. N_2H_4 exhaust temperature (T-2) = ambient

__________ G. Verify that both N_2H_4 flowrate totalizers have been set to zero.

III. Valve System Checkout

__________ A. Open N_2H_4 pressurizing valve (SV-3) and check that N_2H_4 tank pressure (P-1) is near zero.

__________ B. Close N_2H_4 pressurizing valve (SV-3).

__________ C. Energize N_2H_4 pressure regulator (PR-1) and adjust N_2H_4 tank pressure (P-1) to 50 psid.

__________ D. Open N_2H_4 pressurizing valve (SV-3) and note drop in N_2H_4 tank pressure (P-1).

__________ E. Wait for N_2H_4 tank pressure (P-1) to stabilize at 50 psid.

__________ F. Open N_2H_4 vent valve (SV-4) until tank pressure is observed to decrease; immediately close N_2H_4 vent valve (SV-4).

__________ G. Energize GN_2 purge regulator (PR-2) and adjust GN_2 purge pressure (P-3) to 50 psid.

__________ H. Open GN_2 purge valve (SV-5) and note slight decrease in GN_2 purge pressure (P-3).

__________ I. Close GN_2 purge valve (SV-5).

__________ J. Check that N_2H_4 main valve (SV-1) is CLOSED.

__________ K. Open N_2H_4 shutoff valve (SV-2) and verify operation by observing spike in N_2H_4 flowmeter (W-1) reading.

IV. Final System Verification

__________ A. Before initiating N_2H_4 flow, the following checks must be made:

________ 1. GN_2 supply pressure (P-2) holding and steady at 3000 psid.

________ 2. N_2H_4 tank pressure (P-1) holding and steady at 50 psid.

________ 3. GN_2 purge pressure (P-3) holding and steady at 50 psid.

________ 4. N_2H_4 inlet (T-1) and exhaust (T-2) temperature readings are ambient temperature.

________ 5. N_2H_4 flowrate (W-1) reading zero.

________ B. Reset N_2H_4 totalizer to zero.

________ C. Notify On-Scene Commander that N_2H_4 system checks have been completed and system is ready.

V. **Dewatering Phase**

________ A. Obtain permission from On-Scene Commander to initiate N_2H_4 flow.

________ B. Energize N_2H_4 pressure regulator (PR-1) and adjust N_2H_4 tank pressure to selected value; ________ psi.

________ C. Check that N_2H_4 pressurizing valve (SV-3) is open.

________ D. Open N_2H_4 main valve (SV-1) .

________ E. Verify N_2H_4 flow (W-1); ________ cps.

________ F. Verify N_2H_4 reactor operation by noting increase in N_2H_4 exhaust temperature (T-2).

________ G. Notify On-Scene Commander if dry volume differential pressures reach ________ psid.

________ H. Upon breakout of pontoon and salvage object close N_2H_4 main valve (SV-1) and <u>IMMEDIATELY</u> open GN_2 purge valve (SV-5).

________ I. Close N_2H_4 shutoff valve (SV-2).

________ J. Close N_2H_4 pressurizing valve (SV-3).

________ K. Continue GN_2 purge for at least 15 seconds, then close GN_2 purge valve (SV-5).

VI. **N_2H_4 Deactivation Procedure**

________ A. Notify On-Scene Commander of amount of unused N_2H_4, ________ gal. (N_2H_4 flowrate totalizer).

B. **Obtain permission from On-Scene Commander to deactivate N_2H_4 system by either:**

________ Option #1 - Burning unused N_2H_4 through reactor, or

________ Option #2 - Detanking operation at dockside.

C. If Option #1 is selected, proceed as follows

________ 1. Check that N_2H_4 tank pressure (P-1) is at selected value, ______ psid.

________ 2. Check that GN_2 supply pressure (P-2) is sufficient to expel remaining N_2H_4. _____ psid.

________ 3. Check that N_2H_4 inlet temperature (T-1) is less than 200°F.

Note: If (T-1) is greater than 200°F, open GN_2 purge valve (SV-5) and purge reactor until sufficiently cold; then close GN_2 purge valve (SV-5).

________ 4. Check that GN_2 purge valve (SV-5) is closed.

________ 5. Open N_2H_4 main valve (SV-1) and verify N_2H_4 flowrate (W-1) as ______ cps.

________ 6. Verify N_2H_4 reactor operation by noting increase in N_2H_4 exhaust temperature (T-2).

________ 7. Monitor N_2H_4 flowrate (W-1), at first sign of flowrate fluctuation, close N_2H_4 shutoff valve (SV-2).

________ 8. Close N_2H_4 main valve (SV-1).

________ 9. Open GN_2 purge valve (SV-5) and purge reactor for at least 30 seconds.

________ 10. Close GN_2 purge valve (SV-5).

________ 11. Decrease N_2H_4 pressure regulator (PR-1) to zero psid; then turn off.

________ 12. Open N_2H_4 vent valve (SV-4) and leave open until tank pressure reads zero psid.

________ 13. Close N_2H_4 vent valve (SV-4).

________ 14. Close N_2H_4 pressurizing valve (SV-3).

________ 15. Decrease GN_2 purge regulator (PR-2) to zero psid; then turn off.

_______ 16. Recoro GN_2 supply pressure;___psid.

_______ 17. Record N_2H_4 flowrate totalizer reading;______gallons.

_______ 18. De-energize main console power.

_______ 19. De-energize instrumentation main power.

_______ 20. Notify On-Scene Commander than N_2H_4 system is secured.

D. If option# 2 is selected, proceed as follows:

_______ 1. Decrease N_2H_4 pressure regulator (PR-1) to zero psid, then turn off.

_______ 2. Open N_2H_4 vent valve (SV-4) and leave open until tank pressure reads zero psid.

_______ 3. Close N_2H_4 vent valve (SV-4).

_______ 4. Close N_2H_4 pressurizing valve (SV-3).

_______ 5. Close N_2H_4 shutoff valve (SV-2).

_______ 6. Decrease GN_2 purge regulator (PR-2) to zero psid; then turn off.

_______ 7. Open GN_2 purge valve (SV-5) until purge pressure reads zero psid; then close it.

_______ 8. Record GN_2 supply pressure;___psid.

_______ 9. Record N_2H_4 flowrate totalizer reading;______gallons.

_______ 10. De-energize main console power.

_______ 11. De-energize instrumentation main power.

_______ 12. Notify On-Scene Commander than N_2H_4 system is secured.

Appendix B

HYDRAZINE SYSTEM CHECKOUT[d]
(At NCSL, Panama City, Fla.)

I. **Preliminary**

_________ A. Ensure that N_2H_4 support system has been properly installed and that all support bolts are wrench tight.

_________ B. Check that all plumbing connections, fittings, etc., are wrench tight.

_________ C. Check that downstream end of reactor is capped.

_________ D. Check that console power and instrumentation power is off.

_________ E. Connect jumper cable to N_2H_4 console.

_________ F. Energize 110VAC power supply.

_________ G. Verify that the following switches are in the closed (off) position:

  _________ 1. N_2H_4 main valve (SV-1).

  _________ 2. N_2H_4 shutoff valve (SV-2).

  _________ 3. N_2H_4 pressurizing valve (SV-3).

  _________ 4. N_2H_4 vent valve (SV-4).

  _________ 5. GN_2 purge valve (SV-5).

  _________ 6. GN_2 vent valve (SV-6).

  _________ 7. N_2H_4 pressure regulator (PR-1).

  _________ 8. GN_2 purge regulator (PR-2).

_________ H. Energize main console power.

_________ I. Establish voice communication link between console operator and technician at pontoon.

II. **Valve System Checkout**

A. Verify that the following valves are functioning by listening for the solenoid "click".

---

[d] See Figure 11 for schematic and component designations.

________ 1. N_2H_4 main valve (SV-1) ________ open; ________ closed

________ 2. N_2H_4 shutoff valve (SV-2) ________ open; ________ closed

________ 3. N_2H_4 pressurizing valve (SV-3) ____ open; ________ closed

________ 4. N_2H_4 vent valve (SV-4) ________ open; ________ closed

________ 5. GN_2 purge valve (SV-5) ________ open; ________ closed

________ 6. GN_2 vent valve (SV-6) ________ open; ________ closed

________ B. Verify that the following pressure regulators are operating by actuating DC motor.

________ 1. N_2H_4 pressure regulator (PR-1) ____ increase; ____ decrease; _____ off

________ 2. GN_2 purge regulator (PR-2) ____ increase; _____ decrease; _____ off

________ C. Verify that the following hand valves are free to turn, and then <u>CLOSE</u> them.

________ 1. GN_2 fill valve (HV-3) ____________ closed

________ 2. P-2 isolation valve (HV-5) __________ closed

________ 3. GN_2 shutoff valve #1 (HV-7) ________ closed

________ 4. GN_2 shutoff valve #2 (HV-8) ________ closed

________ 5. P-1 isolation valve (HV-4) __________ closed

________ 6. N_2H_4 fill vent valve (HV-2) ________ closed

________ 7. N_2H_4 fill valve (HV-1) ____________ closed

________ 8 P-3 isolation valve (HV-6) __________ closed

III. System Pressure Check

________ A. Remove GN_2 fill cap and attach a regulated GN_2 supply.

________ B. Set supply pressure at 50 psig.

________ C. Using a suitable leak detecting fluid, systematically check all fittings, connections, valves, etc. for leaks using the following sequence, and correct as required.

______ 1. Open GN_2 fill valve (HV-3) and P-2 isolation valve (HV-5); check pressurized components for leaks.

______ 2. Open GN_2 shutoff valves (HV-7 and HV-8); check pressurized components for leaks.

______ 3. Open P-1 isolation valve (HV-4) and energize N_2H_4 pressure regulator (PR-1) until N_2H_4 tank pressure (P-1) reads 50 psig; check pressurized components for leaks.

______ 4. Open N_2H_4 pressurizing valve (SV-3); check pressurized components for leaks, including bottom of N_2H_4 tank.

______ 5. Open N_2H_4 shutoff valve (SV-2); check pressurized components for leaks.

______ 6. Open P-3 isolation valve (HV-6) and energize GN_2 purge regulator (PR-2) until GN_2 purge pressure (P-3) reads 50 psig; check pressurized components for leaks.

______ 7. Open GN_2 purge valve (SV-5); check pressurized components for leaks.

______ 8. Open N_2H_4 main valve (SV-1); check remainder of system for leaks.

IV. **Secure N_2H_4 System**

After all leaks have been sealed, the 50 psig gas pressure will be locked up in the system. Secure the system as follows:

______ A. Close N_2H_4 main valve (SV-1).

______ B. Close N_2H_4 shutoff valve (SV-2).

______ C. Close N_2H_4 pressurizing valve (SV-3).

______ D. De-energize N_2H_4 pressure regulator (PR-1) to 0 psig, then turn off.

______ E. Close GN_2 purge valve (SV-5).

______ F. De-energize GN_2 purge regulator (PR-2) to 0 psig, then turn off.

______ G. Close GN_2 fill valve (HV-3).

______ H. Disconnect pressure test line and secure.

______ I. Cap GN_2 fill line.

_______ J. De-energize main console power.

_______ K. De-energize 110 VAC power supply.

_______ L. Remove jumper cable.

_______ M. Notify cognizant personnel that the N_2H_4 system check is complete.

Appendix C

DOCKSIDE GN_2 CHARGING PROCEDURE[e]

_______ 1. Check to ensure the presence of the following equipment:

- _______ a. GN_2 high volume pressure regulator (PR-4).
- _______ b. GN_2 transfer line (GNL-3).
- _______ c. GN_2 check valve (CV-5).
- _______ d. GN_2 6000 psi bottles (____required).

_______ 2. Open GN_2 shutoff valves (HV-7 and HV-8).

_______ 3. Check that GN_2 fill valve (HV-3) is closed.

_______ 4. Uncap hand valve (HV-3) and attach check valve (CV-5).

NOTE Check flow direction of check valve (CV-5).

_______ 5. Attach pressure regulator (PR-4) to 6000 psi GN_2 bottle.

_______ 6. Attach GN_2 transfer line (GNL-3) to check valve (CV-5) and pressure regulator (PR-4).

_______ 7. Open hand valve (HV-3).

_______ 8. Check that pressure regulator (PR-4) is set for zero pressure.

_______ 9. Open 6000 psi GN_2 bottle hand valve.

_______ 10. Set pressure regulator (PR-4) to 3000 psi and verify GN_2 flow.

_______ 11. When GN_2 flow has stopped, close 6000 psi bottle hand valve.

_______ 12. Reset pressure regulator (PR-4) to zero psi.

_______ 13. Disconnect pressure regulator (PR-4) from 6000 psi GN_2 bottle.

_______ 14. If additional nitrogen is required, replace the 6000 psi bottle with a full one, attach regulator (PR-4) and return to step 8.

_______ 15. When nitrogen requirements have been met, close hand valve (HV-3).

---

[e] See Figure C-1 for schematic and component designations.

_______16. Check that pressure regulator (PR-4) is set for zero psi.

_______17. Disconnect GN_2 transfer line (GNL-3) from regulator (PR-4) and stow regulator.

_______18. Disconnect GN_2 transfer line (GNL-3) from check valve (CV-5), cap and stow GN_2 transfer line.

_______19. Disconnect check valve (CV-5) from hand valve (HV-3) and stow check valve.

_______20. Cap hand valve (HV-3).

_______21. Label and stow all 6000 psi bottles.

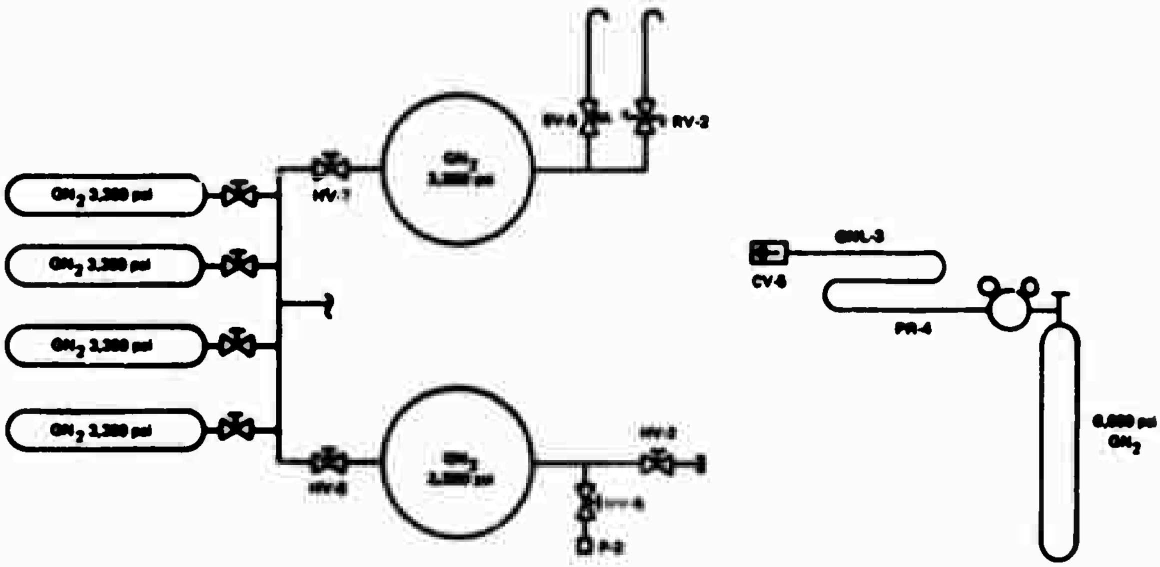

Figure C-1. Piping schematic for charging GN_2 system.

Appendix D

DOCKSIDE N_2H_4 TANKING PROCEDURE[f]

WARNING:

SMOKING AND/OR VEHICULAR TRAFFIC ARE ABSOLUTELY FORBIDDEN IN THE VICINITY. THE AREA SHALL BE BARRICADED AGAINST CASUAL OBSERVERS.

NOTE: Prior to tanking operations a vacuum shall be drawn on the 850-gallon hydrazine fuel tank.

_______ 1. CAUTION: Assure the availability of copious quantities of running water. Always wash down any spilled hydrazine, immediately.

_______ 2. All personnel involved in the transfer operation shall be properly outfitted with required safety clothing:

_______ a. Body:

Coveralls, Rocket Fuel Handler's; Impermeable, full protection for hydrazine, available in 5 sizes (FSN 8415-725-3627 thru 8415-725-3631).

_______ b. Feet:

Boot, Fireman (Rubber); steel toe reinforcement, puncture-proof sole. (FSN 8430-753-5935, 8430-753-5940).

NOTE: Boot tops shall be worn inside (not outside) the trouser legs.

_______ c. Hands:

Gloves, Vinyl, Water and Fuel; Protective (FSN 8415-916-2817 or 8415-916-2818).

NOTE: Gloves shall be sealed by the coverall cuff.

_______ d. Face:

_______ (1) Faceshield, Industrial; Fiber mask with semi-skull and chin guard, thick plastic window.

or

_______ (2) Respirator, MSA Type N, Model SW.

---

[f] See Figure D-1 for schematic and component designations.

_______ 3. Check to ensure the presence of all required fueling component equipments:

_______ a. Small table or work bench.

_______ b. Parts basin (filled with water).

_______ c. GN_2 "K" bottles (_______ required).

_______ d. GN_2 regulator (PR-3).

_______ e. GN_2 pressure line (GNL-1).

_______ f. GN_2 assembly:

_______ (1) Hand valve (HV-10).

_______ (2) Filter (F-3).

_______ (3) Check valve (CV-3). (Check direction of flow.)

_______ (4) Hand valve (HV-12).

_______ (5) 5 psig relief valve assembly (RV-3).

_______ (6) Fuel drum bung connector fitting.

_______ g. Dip tube with check valve (CV-4) attached. (Check direction of flow.)

_______ h. Fuel line assembly:

_______ (1) Fuel transfer line (FL-1).

_______ (2) Filter (F-4).

_______ (3) Hand valve (HV-11).

_______ i. Fuel transfer line (FL-2).

_______ j. Electrical grounding harness and suitable ground.

_______ k. 55-gallon drums of hydrazine (_______ required).

_______ l. Tray of miscellaneous fittings (caps, unions, plugs).

_______ m. Set of tools:

_______ (1) 12-inch crescent

_______ (2) 3/8-inch Allen wrench

_______ (3) large channel locks

_______ (4) diagonal pliers

_______ (5) 1 set end wrenches (3/8" to 1")

_______ n. 2" x 4" wood block, six inches long.

_______ o. Weighing scale, 600 lb. capacity.

_______ p. GN_2 pressure line (GNL-2).

_______ q. High volume GN_2 pressure regulator (PR-4).

_______ r. Vacuum/pressure gauge assembly.

_______ (1) Vacuum/pressure gauge.

_______ (2) Filter (F-5).

_______ s. Leak Tec fluid.

_______ 4. CAUTION: Assure that water hose is turned on.

_______ 5. Assure that all valves are closed.

_______ 6. Back off GN_2 regulator (PR-3) to ensure 0 psig setting.

_______ 7. Uncap and attach GN_2 regulator (PR-3) to GN_2 "K" bottle.

_______ 8. Unplug and attach GN_2 pressure line (GNL-1) to the uncapped GN_2 regulator (PR-3).

_______ 9. Uncap and attach the GN_2 assembly hand valve (HV-10) to the GN_2 pressure line (GNL-1).

_______ 10. Ensure that check valve (CV-3) is oriented for gas flow in the proper direction.

NOTE: Do not attach to the N_2H_4 drum.

_______ 11. Open hand valves (HV-10) and (HV-12).

_______ 12. Open the "K" bottle hand valve (HV-9) and check pressure reading of GN_2 regulator (PR-3).

_______ 13. Detach the bung connector fitting from the GN_2 assembly, at the 1/2" tubing nut on relief valve (RV-3).

_______ 14. Cap relief valve (RV-3) and plug the bung connector tubing nut.

_______ 15. Set the GN_2 regulator (PR-3) to 4 psig, then slowly increase pressure to test the relief setting of relief valve (RV-3).

_______ 16. If relief occurs at 5 psig proceed; otherwise, adjust.

_______ 17. Back off the GN_2 regulator (PR-3) to zero pressure.

_______ 18. Uncap relief valve (RV-3).

_______ 19. Reset the GN_2 regulator (PR-3) to 4 psig. Purge the GN_2 pressurizing line for one or two minutes. Cap relief valve (RV-3).

_______ 20. Close the GN_2 line hand valve (HV-12).

_______ 21. Place the 55-gallon N_2H_4 fuel drum on the weighing scale.

_______ 22. Remove the 2-inch bung cap from the fuel drum and immediately unplug and install the dip tube/check valve (CV-4) assembly. Place the bung cap in a wet parts basin.

_______ 23. Cap check valve (CV-4).

_______ 24. Remove the 3/4-inch bung cap from the fuel drum and immediately replace it with the uncovered bung connector fitting from the GN_2 assembly. Place the bung cap in a wet parts basin.

_______ 25. Unplug and mate the fuel transfer line (FL-2) with uncapped fuel line assembly hand valve (HV-11), valve closed.

_______ 26. Unplug fuel transfer line (FL-2), and mate with the uncapped GN_2 assembly relief valve (RV-3).

_______ 27. Open fuel line assembly hand valve (HV-11).

_______ 28. Uncap fuel line (FL-1).

_______ 29. Open GN_2 assembly hand valve (HV-12). Purge for one or two minutes.

NOTE: Do not back off pressure regulator (PR-3).

_______ 30. Close fuel line hand valve (HV-11).

_______ 31. Plug the open end of fuel transfer line (FL-1).

________ 32. Open fuel line hand valve (HV-11) and check for leaks.

________ 33. Close fuel line hand valve (HV-11).

________ 34. Close GN_2 pressure line hand valve (HV-12).

________ 35. Slowly loosen fuel transfer line (FL-2) at relief valve (RV-3) to relieve pressure.

________ 36. Disconnect the fuel transfer line (FL-2) from relief valve (RV-3).

________ 37. Cap relief valve (RV-3) and plug fuel transfer line (FL-2).

________ 38. Electrical grounding harness.

- ________ a. Attach one branch to the fuel drum.
- ________ b. Attach one branch to the fuel transfer line (FL-2).
- ________ c. Attach one branch to the GN_2 pressure line (GNL-1) at the regulator (PR-[illegible]).
- ________ d. Attach the pigtail to a suitable ground.

________ 39. Uncap the dip tube check valve (CV-4).

________ 40. Examine check valve (CV-4) to assure proper direction of flow.

________ 41. Unplug and mate fuel transfer line (FL-2) to dip tube check valve (CV-4).

________ 42. Unplug the fuel drum bung connector fitting and mate the connector fitting with uncapped GN_2 relief valve (RV-3).

________ 43. Remove the cap and plug from pontoon fuel fill line at hand valve (HV-1) and fuel transfer line (FL-1).

________ 44. Mate fuel transfer line (FL-1) with pontoon fuel fill line hand valve (HV-1).

________ 45. Record the gross weight on the scale =   lbs.

________ 46. Open GN_2 assembly hand valve (HV-12).

________ 47. Open fuel transfer line hand valve (HV-11).

________ 48. Open pontoon fuel fill line hand valve (HV-1).

________ 49. CAUTION: Check for fuel leakage and correct as required, closing GN_2 pressure line hand valve (HV-12) if necessary. Flush away spilled fuel.

FUEL TRANSFER MONITORING ROUTINE

_______ 50. Monitor scale. Observe for indication of completion of fuel transfer by scale-weight and sounds from fuel drum. Adjust regulator (PR-3) as required.

_______ 51. If all required fuel has been transferred, continue with routine for relieving vacuum from the pontoon fuel sphere, beginning at step 76.

_______ 52. If additional fuel is required, proceed with routine for continuing fueling beginning with step 53.

ROUTINE FOR CONTINUING FUELING

_______ 53. Close pontoon fuel fill line hand valve (HV-1). Cap valve (HV-1).

_______ 54. Close fuel transfer line hand valve (HV-11).

_______ 55. Close GN_2 assembly hand valve (HV-12).

_______ 56. Record weight on scale = _______lbs.

_______ 57. Slowly loosen the 1/2" tubing nut at the GN_2 relief valve (RV-3) joining the fuel drum bung connector fitting. Vent drum pressure.

_______ 58. Remove the 1/2" tubing nut from the relief valve (RV-3) and cap relief valve (RV-3).

_______ 59. Plug the tubing nut on the bung connector fitting.

_______ 60. Remove the bung connector fitting from the fuel drum and replace the 3/4-inch bung cap.

_______ 61. Place the bung connector fitting in a wet parts basin.

_______ 62. Disconnect the check valve (CV-4) back-to-back tubing from the dip tube and plug.

_______ 63. Cap the dip tube, remove it from the drum, and place it in the parts basin.

_______ 64. Replace the fuel drum 2-inch bung cap. Flush away any spilled fuel.

_______ 65. Disconnect the electric harness from the fuel drum.

_______ 66. Replace the empty fuel drum with a full drum.

_______ 67. Reconnect the ground wire to the full drum.

_______ 68. Remove the drum 2-inch bung cap and place in a wet parts basin.

_______ 69. Unplug and uncap the dip tube and install in the drum.

_______ 70. Unplug the check valve (CV-4) back-to-back tubing and mate with the uncapped dip tube.

_______ 71. Remove the 3/4-inch bung cap and place it in a wet parts basin.

_______ 72. Install the drum bung connector fitting.

_______ 73. Uncap relief valve (RV-3) and unplug the 1/2-inch tubing nut on the bung connector fitting.

_______ 74. Mate relief valve (RV-3) with the bung connector fitting.

_______ 75. Proceed by returning to step 45.

ROUTINE FOR RELIEVING VACUUM ON FUEL SPHERE

_______ 76. Close fuel line assembly hand valves (HV-11) and (HV-1).

_______ 77. Uncap pontoon GN_2 vent hand valve (HV-2).

_______ 78. Unplug, uncap and install vacuum/pressure gauge assembly on (HV-2).

_______ 79. Unplug and mate 1/2-inch tubing nut of GN_2 pressure line (GNL-2) with the vacuum pressure gauge assembly.

_______ 80. Obtain a second GN_2 "K" bottle and attach the high volume GN_2 pressure regulator (PR-4).

_______ 81. Back off the GN_2 regulator (PR-4) to zero pressure.

_______ 82. Open the "K" bottle hand valve (HV-9) and check pressure.

_______ 83. Uncap regulator and unplug (GNL-2) and mate.

_______ 84. Adjust high volume regulator (PR-4) to desired GN_2 flow.

_______ 85. Open pontoon vent hand valve (HV-2).

_______ 86. Monitor vacuum/pressure gauge by closing "K" bottle hand valve (HV-9) periodically until pontoon fuel sphere vacuum has been relieved.

_______ 87. Close "K" bottle hand valve (HV-9).

_______ 88. Back off high volume GN_2 regulator (PR-4) to zero pressure.

_______ 89. Close pontoon vent hand valve (HV-2).

_______ 90. Disconnect vacuum/pressure gauge assembly from hand valve (HV-2) and cap valve (HV-2).

_______ 91. Disconnect nitrogen line (GNL-2) 1/2-inch tubing nut from vacuum/pressure gauge assembly.

_______ 92. Cap, plug and stow the vacuum/pressure gauge assembly.

_______ 93. Detach nitrogen line (GNL-2) from the pressure regulator (PR-4), plug and stow line (GNL-2).

_______ 94. Remove the pressure regulator (PR-4) from the "K" bottle, cap and stow regulator.

_______ 95. Check pontoon fill line hand valve (HV-1) to be sure it is closed.

_______ 96. Record weight on scale = _____ lbs.

_______ 97. Close GN_2 assembly hand valve (HV-12).

_______ 98. Slowly loosen the bung connector fitting 1/2-inch tubing nut at the relief valve (RV-3). Relieve drum pressure.

_______ 99. Disconnect the check valve (CV-4) tubing back-to-back from the dip tube. Cap the dip tube.

_______ 100. Disconnect relief valve (RV-3) from the bung connector fitting 1/2-inch tubing nut.

NOTE: Do not plug or cap either end.

_______ 101. Mate relief valve (RV-3) with check valve (CV-4) tubing back-to-back.

_______ 102. Disconnect fuel transfer line (FL-1) from pontoon fuel fill line hand valve (HV-1). Cap valve (HV-1).

_______ 103. Flush down any spilled fuel.

_______ 104. Uncap the dip tube and mate with fuel transfer line (FL-1).

_______ 105. Open fuel line assembly hand valve (HV-11) and GN_2 assembly hand valve (HV-12).

_______ 106. Elevate the combined assemblies and lines above the fuel drum and purge all trapped fuel back to the fuel drum.

_______ 107. Close GN_2 assembly hand valves (HV-12) and (HV-10).

_______ 108. Plug the tubing nut on the bung connector fitting.

_______ 109. Disconnect the check valve (CV-4) tubing back-to-back from relief valve (RV-3).

_______ 110. Plug tubing nut on check valve (CV-4).

_______ 111. Disconnect fuel line (FL-1) from the dip tube and plug fuel line (FL-1).

NOTE: Do not cap dip tube.

_______ 112. Remove grounding harness from fuel line (FL-2).

_______ 113. Remove dip tube and replace the 2-inch bung cap.

_______ 114. Flush, dry, plug and cap, and stow dip tube.

_______ 115. Unplug and flush fuel line assembly and fuel lines.

_______ 116. Flush open part of relief valve (RV-3).

_______ 117. Dry fuel line assembly by passing GN_2 through it.

_______ 118. Disconnect fuel lines (FL-1) and (FL-2) from the fuel line assembly.

_______ 119. Plug, cap and stow the fuel lines and fuel line assembly.

_______ 120. Cap relief valve (RV-3).

_______ 121. Back off pressure regulator (PR-3).

_______ 122. Disconnect GN_2 line (GNL-1) from hand valve (HV-10) and plug line

_______ 123. Cap hand valve (HV-10).

_______ 124. Remove bung connector fitting and place in wet parts basin.

_______ 125. Replace 3/4-inch bung cap in fuel drum.

_______ 126. Unplug bung connector fitting tubing nut and rinse fitting thoroughly.

_______ 127. Dry and purge bung connector fitting with GN_2.

_______ 128. Uncap relief valve (RV-3) and mate to bung connector fitting.

_______ 129. Cover the bung fitting and stow the GN_2 assembly.

_______130. Close "K" bottle hand valve (HV-9).

_______131. Remove grounding harness from nitrogen line (GNL-1).

_______132. Disconnect GN_2 pressure line (GNL-1) from the GN_2 regulator (PR-3); plug and stow line.

_______133. Disconnect GN_2 regulator (PR-3) from the GN_2 "K" bottle; cap and stow regulator.

_______134. Prepare GN_2 "K" bottles for stowage.

_______135. Disconnect grounding harness from fuel drum and stow.

_______136. Prepare the fuel drum, PROPERLY LABELED.

_______137. Stow all support equipment.

_______138. Post "No Smoking" signs on dock area in the vicinity of the hydrazine system.

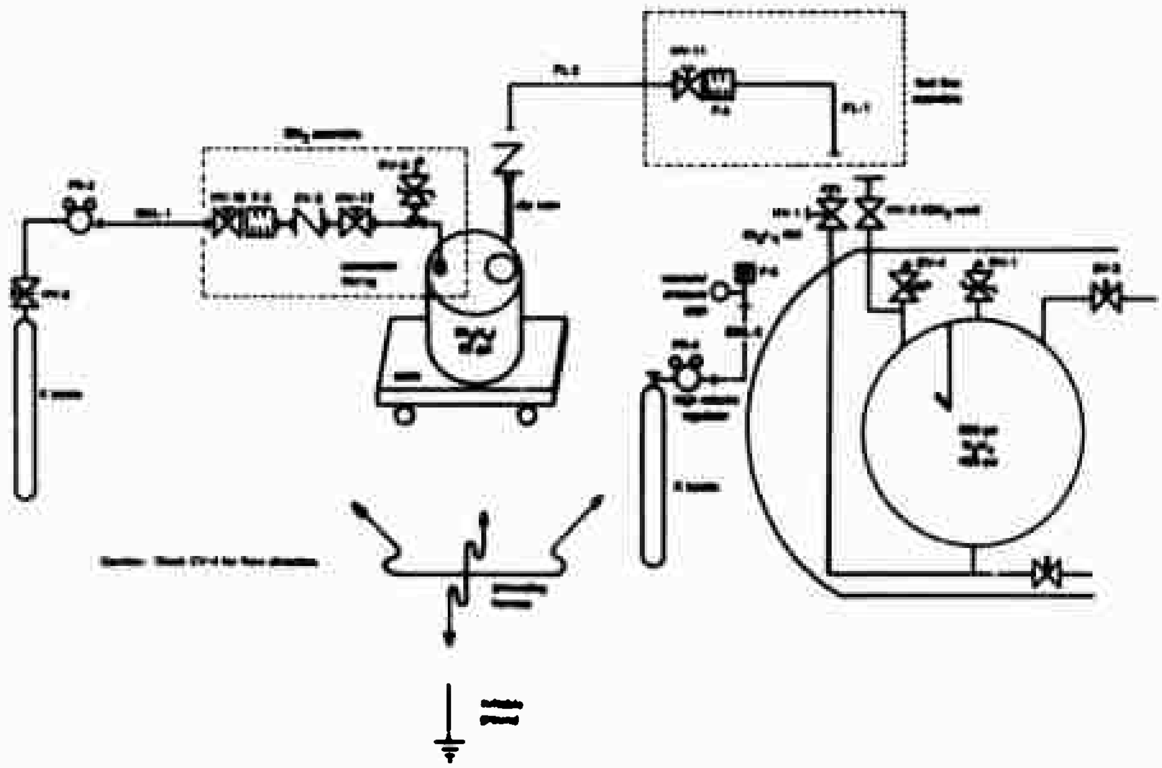

Figure D-1. Piping schematic for hydrazine tanking procedure.

Appendix E

DOCKSIDE N_2H_4 DE-TANKING PROCEDURE[g]

WARNING:

SMOKING AND/OR VEHICULAR TRAFFIC ARE ABSOLUTELY FORBIDDEN IN THE VICINITY. THE AREA SHALL BE BARRICADED AGAINST CASUAL OBSERVERS.

_______ 1. CAUTION: Assure the availability of copious quantities of running water. Always wash down any spilled hydrazine, immediately.

_______ 2. All personnel involved in the transfer operation shall be properly outfitted with required safety clothing:

_______ a. Body:

Coveralls, Rocket Fuel Handler's; Impermeable, full protection for hydrazine, available in 5 sizes (FSN 8415-725-3627 thru 8415-725-3631).

_______ b. Feet:

Boot, Fireman (Rubber); steel toe reinforcement, puncture-proof sole. (FSN 8430-753-5935, 8430-753-5940).

NOTE: Boot tops shall be worn inside (not outside) the trouser legs.

_______ c. Hands:

Gloves, Vinyl, Water and Fuel; Protective (FSN 8415-916-2817 or 8415-916-2818).

NOTE: Gloves shall be sealed by the coverall cuff.

_______ d. Face:

_______ (1) Faceshield, Industrial; Fiber mask with semi-skull and chin guard, thick plastic window.

or

_______ (2) Respirator, MSA Type N, Model SW

_______ 3. Check to ensure the presence of all required fueling component equipments:

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[g] See Figure E-1 for schematic and component designations.

_______ a. Small table or work bench.

_______ b. Parts basin (filled with water).

_______ c. GN_2 "K" bottles (_____ required)

_______ d. GN_2 regulator (PR-3).

_______ e. GN_2 pressure line (GNL-1).

_______ f. GN_2 assembly:

  _______ (1) Hand valve (HV-10).

  _______ (2) Filter (F-3).

  _______ (3) Check valve (CV-3). (Check direction of flow.)

  _______ (4) Hand valve (HV-12).

  _______ (5) 5 psig relief valve assembly (RV-3).

  _______ (6) Fuel drum bung connector fitting.

_______ g. Dip tube with check valve (CV-4) attached. (Check direction of flow.)

_______ h. Fuel line assembly:

  _______ (1) Fuel transfer line (FL-1).

  _______ (2) Filter (F-4).

  _______ (3) Hand valve (HV-11).

_______ i. Fual transfer line (FL-2).

_______ j. Electrical grounding harness and suitable ground.

_______ k. Empty 55-gallon hydrazine drums (_______ required).

_______ l. Tray of miscellaneous fittings (caps, unions, plugs).

_______ m. Set of tools:

  _______ (1) 12-inch crescent.

  _______ (2) 3/8-inch Allen wrench.

_______ (3) large channel locks.

_______ (4) diagonal pliers.

_______ (5) 1 set end wrenches (3/8" to 1").

_______ n. 2" x 4" wood block, six inches long.

_______ o. Weighing scale, 600 lb. capacity.

_______ p. GN_2 pressure line (GNL-2).

_______ q. Leak Tec Fluid.

_______ 4. Ensure that the following pontoon conditions exist:

_______ a. Cap installed on pontoon N_2H_4 fuel fill line.

_______ b. Pontoon fuel fill line hand valve (HV-1) closed.

_______ c. Pontoon GN_2 vent hand valve (HV-2) closed and capped.

_______ 5. Ascertain the N_2H_4 fuel volume (gallons) to be transferred.

_______ 6. Provide sufficient quantity of empty 55-gallon stainless steel (N_2H_4 rated) fuel drums to accomodate fuel to be transferred.

_______ 7. CAUTION Assure that water hose is turned on.

_______ 8. Uncap and attach the GN_2 regulator (PR-3) to a GN_2 "K" bottle.

_______ 9. Unplug and attach the GN_2 pressure line (GNL-1) to the GN_2 regulator (PR-3).

_______ 10. Uncap and attach the GN_2 assembly to the GN_2 pressure line (GNL-1).

_______ 11. Ensure GN_2 assembly hand valves (HV-10) and (HV-12) are closed.

_______ 12. Set GN_2 regulator (PR-3) to 0 psig.

_______ 13. Open "K" bottle hand valve (HV-9) and check "K" bottle pressure.

_______ 14. Adjust GN_2 regulator (PR-3) to 4 psig.

_______ 15. Remove covering from bung connector fitting.

_______ 16. Open hand valves (HV-10) and (HV-12) and purge the pressure line assembly for one or two minutes.

_______17. Close GN_2 assembly hand valve (HV-12).

_______18. Disconnect the bung connector fitting from the relief valve (RV-3) at the 1/2-inch tubing nut on relief valve (RV-3).

_______19. Cap relief valve (RV-3).

_______20. Remove the 3/4-inch bung cap from the empty fuel drum and place it in the wet parts basin.

_______21. Plug the bung connector fitting and install the fitting in the empty drum.

_______22. Open hand valve (HV-12) and test relief valve (RV-3) for opening at 5 psig.

_______23. If (RV-3) opens properly, back off regulator (PR-3).

_______24. Disconnect the hand valve (HV-12) back-to-back from the check valve (CV-3).

_______25. Cap check valve (CV-3) and uncap relief valve (RV-3).

_______26. Mate relief valve (RV-3) with the unplugged 1/2-inch tubing nut of the bung connector fitting.

_______27. Close hand valves (HV-12) and (HV-10).

_______28. Place empty fuel drum on the weighing scale.

_______29. Remove the 2-inch fuel drum bung cap and place it in the wet parts basin.

_______30. Immediately uncap, unplug and install the dip tube with check valve (CV-4).

_______31. Cap the check valve (CV-4).

_______32. Obtain the electrical grounding harness and ensure availability of a suitable ground.

    _______ a. Attach one branch of the harness to the empty fuel drum.

    _______ b. Attach one branch to the GN_2 regulator (PR-3).

    _______ c. Attach the pig tail to the ground.

    _______ d. Attach one branch to fuel transfer line (FL-2).

_______33. Uncap and attach the fuel transfer assembly hand valve (HV-11) to the unplugged fuel transfer line (FL-2).

_______34. Close hand valve (HV-11).

________ 35. Examine check valve (CV-4) to assure proper direction of flow.

________ 36. Uncap check valve (CV-4), unplug fuel line (FL-2), and mate them.

________ 37. Unplug fuel line (FL-1), uncap check valve (CV-3), and mate.

________ 38. Set GN_2 regulator (PR-3) to 4 psig.

________ 39. Open (HV-12) and then open (HV-11).

________ 40. Purge for three minutes.

________ 41. Close hand valve (HV-12) and adjust regulator (PR-3) until relief valve (RV-3) relieves.

________ 42. Back off pressure regulator (PR-3) enough to hold pressure in the line and check for leaks.

________ 43. Close hand valve (HV-10).

________ 44. Open hand valve (HV-12) and vent off drum pressure.

________ 45. Close hand valve (HV-11).

________ 46. Disconnect fuel line (FL-1) from check valve (CV-3). Cap check valve (CV-3).

________ 47. Attach fuel line (FL-1) to the uncapped pontoon fuel fill line at hand valve (HV-1).

________ 48. Weigh the drum and record weight = lbs.

________ 49. Open pontoon hand valve (HV-1) and fuel line hand valve (HV-11).

________ 50. Vent pressure and then close hand valve (HV-12).

________ 51. Uncap pontoon vent valve (HV-12) and unplug and attach GN_2 line (GNL-2).

________ 52. Uncap check valve (CV-3) and unplug and attach nitrogen line (GNL-2).

________ 53. Open hand valves (HV-12) and (HV-10), then (HV-2).

________ 54. Monitor "K" bottle pressure at pressure regulator (PR-3). Increase pressure until fuel begins to flow. Verify by monitoring the scale.

________ 55. Record the GN_2 line pressure = ________ psig.

________ 56. CAUTION: Check for leaks. Wash down with fresh water as necessary.

________ 57. If there is insufficient pressure in the first GN_2 "K" bottle to initiate fuel flow or to complete fuel transfer, back off the regulator (PR-3) and close GN_2 hand valves (HV-9) and (HV-10). Skip to step 60.

________58. If the N_2H_4 drum is filled but detanking is not complete, record weight = ____lbs. and skip to step 69.

________59. If detanking has been completed, record weight = ______lbs. and skip to step 87.

ROUTINE FOR CHANGING GN_2 "K" BOTTLES

________60. Disconnect pressure regulator (PR-3) from the empty "K" bottle and install on a full GN_2 "K" bottle.

________61. Loosen the nitrogen line (GNL-1) tubing nut at hand valve (HV-10).

________62. Set the regulator (PR-3) to 4 psig.

________63. Open "K" bottle hand valve (HV-9).

________64. Vent briefly, then tighten the loosened nitrogen line (GNL-1) tubing nut.

________65. Test for leaks.

________66. Open hand valve (HV-10).

________67. Increase pressure regulator (PR-3) setting as necessary to initiate fuel flow.

________68. Return to step 56.

ROUTINE FOR CONTINUING DETANKING

________69. If more than one drum of fuel is to be transferred, monitor the fuel drum hand valve (HV-12) and scale.

________70. When the scale weight gives indication of drum being filled or fuel nears open hand valve (HV-12), close pontoon hand valve (HV-1) and fuel line hand valve (HV-11).

________71. Record the weight on the scale = ______lbs.

NOTE: The volume of fuel transferred can be calculated. Mark the drum with fuel volume.

________72. Disconnect fuel check valve (CV-4) from back-to-back on dip tube and cap valve (CV-4).

________73. Remove dip tube and place in wet parts basin.

________74. Replace 2-inch bung cap.

________75. Disconnect electrical harness from the fuel drum.

________76. Remove bung connector fitting subassembly and place in wet parts basin.

________ 77. Replace 3/4-inch bung cap. Flush away spilled fuel with fresh water.

________ 78. Replace filled fuel drum with empty fuel drum on scale.

________ 79. Attach electrical grounding harness to empty drum.

________ 80. Remove 2-inch bung cap and place it in wet parts basin.

________ 81. Install dip tube in drum.

________ 82. Uncap check valve (CV-4) and mate with dip tube.

________ 83. Remove 3/4-inch bung cap and place in wet parts basin.

________ 84. Install bung connector subassembly. Record weight = lbs.

________ 85. Open hand valves (HV-11) and (HV-1).

________ 86. Return to step 55.

ROUTINE FOR COMPLETION OF DETANKING

________ 87. When it has been determined that all fuel has been removed (by virtue of GN_2 bubbling into the drum), close GN_2 hand valves (HV-10) and (HV-2). Record weight = lbs.

________ 88. Close pontoon hand valve (HV-1).

________ 89. Disconnect fuel line check valve (CV-4) from the back-to-back on the dip tube.

________ 90. Remove the dip tube and place in wet parts basin.

________ 91. Replace the 2-inch bung cap.

________ 92. Disconnect the grounding harness from the fuel drum.

________ 93. Remove the bung connector subassembly and place in a wet parts basin.

________ 94. Replace the 3/4-inch bung cap.

________ 95. Flush away spilled fuel with fresh water.

________ 96. Calculate fuel content of drums. Mark drum(s) with quantities. Prepare for stowage.

________ 97. Disconnect nitrogen line (GNL-2) from hand valve (HV-2) and cap valve (HV-2).

________ 98. Flush open end of nitrogen line (GNL-2) with water.

________ 99. Open hand valve (HV-10) for one minute, then close valve (HV-10).

________100. Disconnect nitrogen line (GNL-2), cap both ends and stow.

________101. Flush bung connector subassembly and mate with check valve (CV-3).

________102. Open hand valve (HV-10) and dry the subassembly, then close valve (HV-10).

________103. Close "K" bottle hand valve (HV-9).

________104. Disconnect hand valve (HV-10) from nitrogen line (GNL-1) and cap valve (HV-10).

________105. Cover the bung fitting and stow the assembly.

________106. Disconnect fuel line (FL-1) from hand valve (HV-1) and cap valve (HV-1).

________107. Disconnect the electrical harness from fuel line (FL-2), pressure regulator (PR-3) and ground. Stow.

________108. Attach the dip tube to check valve (CV-4) and flush the assembly.

________109. Dry the assembly by passing GN_2 through it.

________110. Disconnect check valve (CV-4) from fuel line (FL-2) and cap valve (CV-4).

________111. Plug the dip tube and stow.

________112. Disconnect fuel line (FL-2) from the fuel assembly; plug and stow.

________113. Cap hand valve (HV-11), plug fuel line (FL-1), and stow.

________114. Disconnect nitrogen line (GNL-1); plug and stow.

________115. Disconnect pressure regulator (PR-3); back off, cap and stow.

________116. Prepare "K" bottle(s) for stowage.

________117. Prepare miscellaneous equipment for stowage.

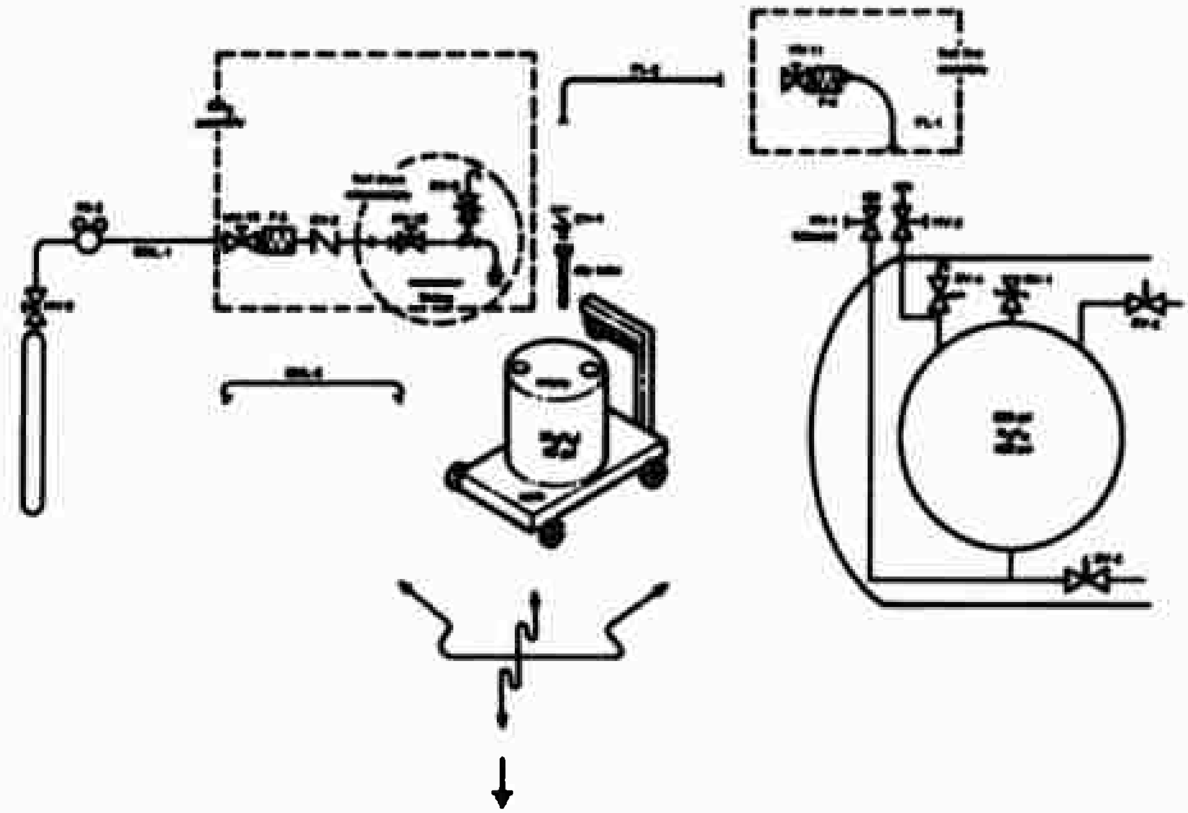

Figure E-1. Piping schematic for hydrazine de-tanking procedure.

REFERENCES

1. U.S. Navy Special Projects Office. "Deep submergence systems project," U.S. Navy briefing to industry, Washington, D.C., 24 Nov 1964.

2.______. DSSP Large object salvage study. General Dynamics Electric Boat Division, Ocean Systems Incorporated, Merritt-Chapman and Scott, Sep 1966 (Contract NO sp 65185-C).

3. Naval Ordnance Systems Command. NAVORD OP 3199, Volume 2: Handling and storage of liquid propellants. Washington, D.C., Jan 1970.

4. Jet Propulsion Laboratory. Report Number 20-77: Basic factors involved in the design and operation of catalytic monopropellant-hydrazine reaction chambers, by A. F. Grant, Jr., Pasadena, Calif., Dec 1954.

5. Naval Weapons Center. Technical Publication 5367: Decomposition of hydrazine on Shell 405 catalyst at high pressure-part 1, 500-5000 psi, by Stanley E. Wood and James T. Bryant. China Lake, Calif., Dec 1972.

6. Bruce W. Schmitz, Duane A. Williams, William W. Smith, and David Maybee. "Design and scaling criteria for monopropellant hydrazine rocket engines and gas generators employing Shell 405 catalyst," paper presented at AIAA Second Propulsion Joint Specialist Conference, Colorado Springs, Colo , Jun 13-17, 1966. (AIAA paper no. 66-594)

7. Forrest S. Forbes and Douglas D. Huxtable. "Monopropellant catalyst evaluation," paper presented at Third International Conference of Space Technology, Rome, Italy, 3-8 May 1971.

8. Air Force Rocket Propulsion Laboratory. Technical Report AFRPL-TR-70-107: Hydrazine catalyst evaluation, by D. D. Huxtable, P. R. Rice, and O. I. Smith. Edwards, Calif., Nov 1970.

9. Jet Propulsion Laboratory. Technical Report 32-1227: The status of monopropellant hydrazine technology, by T. W. Price and D. D. E. Evans. Pasadena, Calif., Feb. 15, 1968.

10. Rocket Research Corporation. RRC-66-R-76, Volume I and Volume II: Development of design and scaling criteria for monopropellant hydrazine reactors employing Shell 405 spontaneous catalyst. Seattle, Wash., 19 Jan 1967. NASA Contract NAS-7-372.

11. Battelle Memorial Institute. Columbus Laboratories. Unnumbered report: Summer 1971 capability demonstration of the Large-Object Salvage System (LOSS) to the U.S. Navy Supervisor of Salvage, by D. J. Hackman and W. S. Pope. Columbus, Ohio, Mar 1972.